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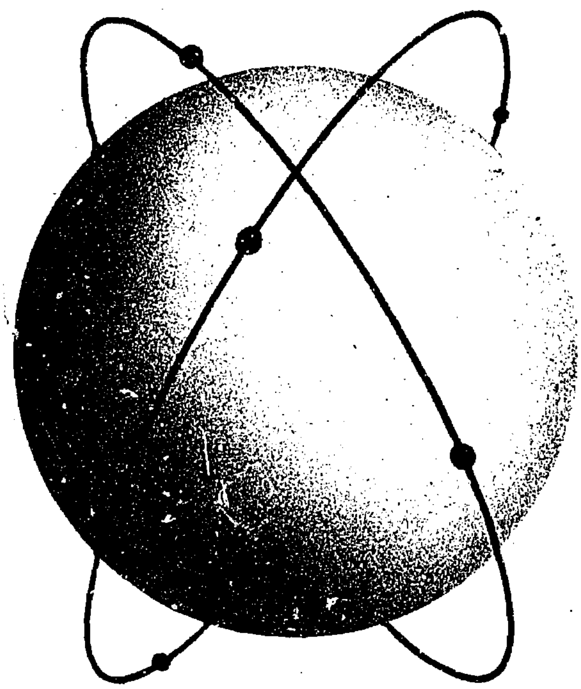
ABSTRACT

As the twelfth lesson of the Articulated Multimedia Physics Course, instructional materials are presented in this study guide with relation to work, energy, and power. The topics are concerned with kinetic and potential energy, energy transfer in free falling bodies, and conservation laws. The content is arranged in scrambled form, and the use of matrix transparencies is required for students to control their learning activities. Students are asked to use magnetic tape playback, instructional tapes, and single concept films at the appropriate place in conjunction with the worksheet. Included are a homework problem set and illustrations for explanation purposes. Related documents are SE 015 963 through SE 015 977. (CC)

ARTICULATED MULTIMEDIA PHYSICS



LESSON 12

NEW YORK INSTITUTE OF TECHNOLOGY
OLD WESTBURY, NEW YORK

NEW YORK INSTITUTE OF TECHNOLOGY

Old Westbury, Long Island

New York, N.Y.

ARTICULATED MULTIMEDIA PHYSICS

Lesson Number 12

WORK, ENERGY, AND POWER

IMPORTANT: Your attention is again called to the fact that this is not an ordinary book. It's pages are scrambled in such a way that it cannot be read or studied by turning the pages in the ordinary sequence. To serve properly as the guiding element in the Articulated Multimedia Physics Course, this Study Guide must be used in conjunction with a Program Control equipped with the appropriate matrix transparency for this Lesson. In addition, every Lesson requires the availability of a magnetic tape playback and the appropriate cartridge of instructional tape to be used, as signaled by the Study Guide, in conjunction with the Worksheets that appear in the blue appendix section at the end of the book. Many of the lesson Study Guides also call for viewing a single concept film at an indicated place in the work. These films are individually viewed by the student using a special projector and screen; arrangements are made and instructions are given for synchronizing the tape playback and the film in each case.

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Energy is a familiar word. You say it or think about it often in your everyday life. After a tingling shower in the morning, you may feel fit and full of energy, ready for the tasks of the day. As the hours pass and you perform the jobs you must do to further your education or help you make a living, you gradually become tired. By the time dinner is through, you may say that you have little energy left. A good night's sleep, a nourishing breakfast, and you're prepared to repeat the performance of the previous day, your energy having been restored. In many ways, this common use of the energy idea is closely related to the scientist's definition of it, but it is a little too loose for the physicist's needs.

Speaking of everyday things that tie in with the concept of energy, we might mention fuels as having a strong connection with energy. The food you eat is the fuel that supplies your muscular energy; the gasoline in your automobile provides the energy it needs to climb a hill or to keep moving against the interminable retardation of friction and air resistance; the coal, oil, or wood in the engine supplies the energy needed to run a train, plow a field, or lift the girders used in building a skyscraper. The energy of the sun, stored in growing things and waterfalls, is the result of the consumption of atomic "fuel."

Please go on to page 2.

Energy, regardless of its source or kind, is almost always involved in doing a job. Lifting a hammer, speeding up a train, running a lawnmower, and just walking about are jobs that use fuel. Such fuel-using jobs can be done because of energy that is converted from one form to another. We start with an energy-source and then, by transferring this energy from one form to another, we make it suitable for the task at hand. We know of no method or technique whereby energy can be created out of nothing; we can change it, move it about from one place to another, and design new and better devices to use it, but we cannot make it.

Rather than try to define energy prematurely, let us state in detail why we believe that energy is involved in the fuel-using jobs described above. We know, first of all, that an unbalanced force must be acting when we lift a hammer, mow a lawn, or climb a tree; then, as a result of the unbalanced force, something moves. So we can start by saying that energy is involved if an unbalanced force causes motion, or produces certain types of changes in motion. This will have to do for the moment; but be assured that we shall not stop with this hazy description of energy.

Please go on to page 3.

When forces are exerted and things move, energy is converted from one form to another or transferred from one object to another. When such conversions or transfers occur, we say that work has been done. So you see, the concept of work is inextricably interwoven with the concept of energy; you can hardly speak of one of them without bringing the other into the discussion. In a sense, work is the measure of the job done. For instance, if a derrick lifts one car it has done a certain amount of work; if it then lifts a second, identical car to the same height as the first, the total job (or work done) is twice that involved in lifting the first car alone. In another sense, work is the measure of the fuel used to do a job. Clearly, the fuel needed to lift two cars to a given height is twice that required to lift one of them if both cars are identical. The two ideas are quite the same, both of them implying that work is a measure of the energy converted or transferred.

Many of our questions could be answered if we could find a combination of force and motion that would serve as a measure of energy transfer. Our objective, then, is to find some such combination which is proportional to the fuel used and to the total size of the job done. This combination of force and motion could then represent work; so, for our present purposes, any quantity we call "work" must be proportional to the magnitude of the task accomplished, or to the fuel used to accomplish it.

Please go on to page 4.

To help us arrive at a definition of work which meets the requirements outlined in the introduction to this lesson, we shall analyze the factors that go into the performance of a specific job such as that pictured in Figure 1.

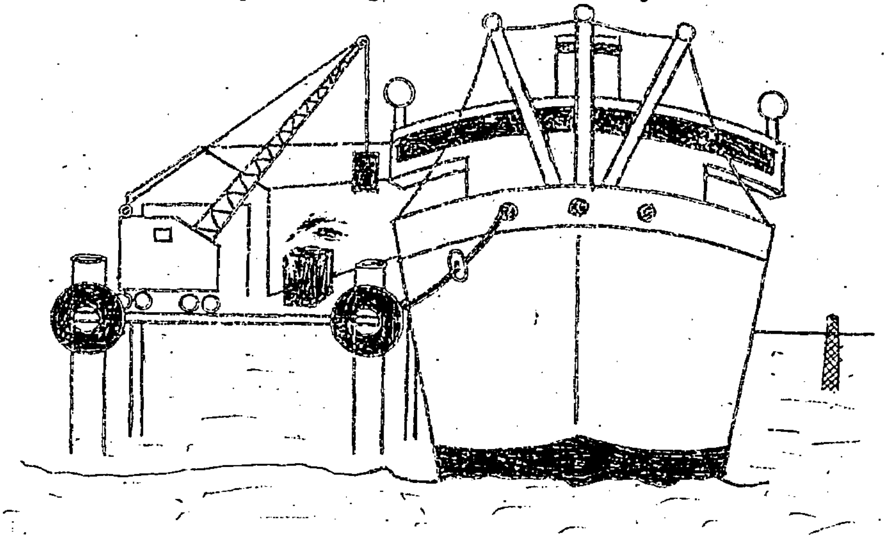

Figure 1

A number of crates, each having exactly the same weight, are to be hoisted to the deck of a freighter standing in a harbor. The job is to be done by a gasoline-drive crane on the dock. What we want to know is this: What governs the amount of fuel (gasoline) used in accomplishing this job?

Well, consider the weight of the crates first. To lift a single crate, the crane must exert enough force on it to overcome the pull of gravity and start the crate moving away from the ground. Suppose that a single crate is so heavy that the crane can lift only one at a time. If the foreman on the job wanted to speed up the work and load two at a time, he might bring a second crane to the dock so that both could work simultaneously. Then, in this case as the crates went up, the total force would be <u>twice</u> that exerted by a single crane but the fuel used would also be <u>twice</u> than of a single crane. Evidently, the fuel consumption is proportional to the force applied by the machine. But, as you read in the introduction, <u>work</u> is to be measured in terms of the fuel used to accomplish a job. So, tentatively at least, what might we conclude?

(1)

A The work done is inversely proportional to the force.

B The work done is directly proportional to the force.

YOUR ANSWER --- B

Just how did you reach this conclusion? Since 288 is just 2/3 of 432, it may be that you thought of t = 3.00 sec as representing the beginning of the third second. Thus, you may have thought that the K.E. remaining in the ball is 2/3 of the original before free-fall began. This is incorrect.

Properly, t = 0 marks the instant you start your stop-watch, t = 1 is one second later, t = 2 is after a lapse of two seconds, and t = 3 marks the passing of three seconds.

Do you remember the total time for the fall?

Where will the ball be after it has been falling for three seconds? When the ball reaches the ground, all of the original P.E. becomes K.E.

Please return to page 76. Pick a better answer this time.

YOUR ANSWER --- B

Very good. If our definition of work as a measure of energy transfer is to be of any value, then we must agree that force F_T does no work at all. No fuel is used to produce F_T, no energy is consumed, hence no work is done.

We can improve our description of the meaning of "work" now. Work is the product of an unbalanced force and the distance moved in the direction of the force. This could suffice as a definition of work for most situations; but for universal application, it still needs some improvement. Look at the force in Figure 4.

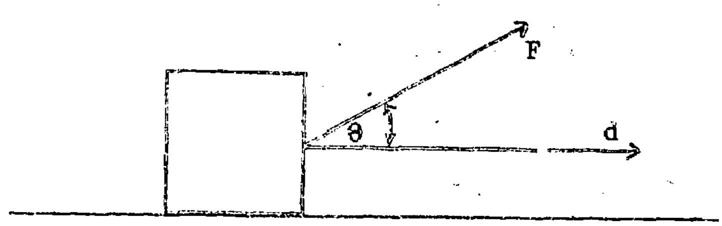

Figure 4

This force (F) acts at an angle θ to the horizontal, but the block moves horizontally along the table. According to the above definition, the block does not move in the direction of the force. If you adhere strictly to the definition, you must conclude that force F does no work at all. But you KNOW that energy must be expended in moving the block horizontally against friction; hence work has to be accomplished. How do we resolve this dilemma?

Think back to resolution of vectors. Force F may be considered to be made up of two parts: a horizontal component and a ________ component. What's the missing word? Turn to page 75 to check.

YOUR ANSWER --- A

The mathematical statement of the Second Law does NOT state that $F = a/m$. Perhaps you need to review your notes, although you should remember that acceleration is directly proportional to unbalanced force and inversely proportional to the mass of the body being accelerated.

Please return to page 91 and make a better selection.

YOUR ANSWER --- A

This is incorrect.

One of the answers definitely <u>does</u> express the meaning of $\frac{\Delta d}{\Delta t}$ properly.

Please return to page 88 and see if you can decide which of the given answers does this.

YOUR ANSWER --- B

Not quite.

The substitution yields this first result:

$$W = m \times \underbrace{\frac{v^2}{2d}}_{a} \times d$$

But when this is simplified, you don't get the answer you chose.

So, return to page 82, please and select a better answer.

YOUR ANSWER --- C

This is incorrect on two counts!

First, if the watt is a unit of power, the watt-second cannot possibly measure power, which is the rate of doing work.

Second, if the watt-second were truly a unit of power, it could not be the same as a joule, since the latter is a unit of work or energy!

Come now. If you will bear in mind that a watt and a joule per second are identical units, you should have no difficulty in choosing the right answer.

Please return to page 140 and try once more.

YOUR ANSWER --- A

This doesn't follow from our reasoning.

Every drop of gasoline used by the crane engine can rotate the cable drum just so much. To lift a crate twice the distance, the drum would have to complete twice as many revolutions. If each drop of gasoline can account for just so many turns, you can't expect the drum to turn twice as many times without using more gasoline.

Please return to page 40. Choose a better answer.

YOUR ANSWER --- B

A kilowatt uses the same prefix as a kilometer. This prefix always means "1,000 times"; hence, a kilowatt is 1,000 watts.

The watt is a unit of power; so is the kilowatt. If we multiply a power unit such as the kilowatt by a time unit such as the hour, we cannot obtain a power unit from the product.

Thus, a kilowatt-hour is not a unit of power. To find out what it really measures, do this:

$$\text{kw-hr} = \text{power} \times \text{time}$$

$$\text{power} = \frac{\text{work}}{\text{time}}$$

so— $$\text{kw-hr} = \frac{\text{work}}{\text{time}} \times \text{time}$$

So what is the kilowatt-hour?

Please return to page 145 and choose the right answer now.

YOUR ANSWER --- A

There are several things wrong with the answer you chose.

You cannot equate two different kinds of quantities. Distance moved is a single, fundamental measure of displacement while work is a combination of force and motion and cannot possibly be equal to distance.

As an example which shows the fallacy of this kind of statement, consider a box containing marbles. It is safe to say that the weight of the box depends upon the number of marbles in the box, but you could never say that the weight is equal to the number of marbles. Suppose the box contains 173 marbles and weighs 2.9 lb. It wouldn't be correct to write 2.9 lb = 173 marbles.

From the point of view of units alone, you can't have an equation with units of different meaning on either side of the equal sign.

Please return to page 56 and choose an alternative answer.

YOUR ANSWER --- B

You're confusing energy and momentum. Find the total momentum of the system, not the total kinetic energy.

Return to the original question on page 127 and read the explanatory material once more--carefully. Then choose a better answer.

This page has been inserted to maintain continuity of text. It is not intended to convey lesson information.

YOUR ANSWER --- B

You chose the wrong component. We're quite sure you realized that the work done here must be the product of the horizontal component of F and the displacement d. But F_V is the symbol for the vertical component; this component does no work, of course, because there is no vertical motion in the system.

Please return to page 75 and choose the right answer.

YOUR ANSWER --- B

We are aware of the thinking that led you to choose this answer. You figured that, if 147 joules of work were expended in getting the block to the top of the shelf, then 147 joules of kinetic energy must have been transferred to it, since no energy is being lost to friction. Up to a point this is good thinking, but it falls short of the truth because the motionless block has no velocity on the shelf; hence, it cannot have kinetic energy. That is, since

$$K.E. = \frac{1}{2}mv^2$$

and $v = 0$, then K.E. must be zero.

This may make you wonder what happened to the work that went into raising the block to the shelf. And well it should!

We'll help you out of this dilemma shortly.

In the meantime, you will have to return to page 150 and then select the only possible answer.

YOUR ANSWER --- B

We are almost certain that you arrived at this answer as a result of two separate but common errors.

The determination of the K.E. of the bullet as it leaves the muzzle of the rifle calls for the solution of:

$$K.E. = \frac{1}{2}mv^2$$

In substituting, you must be sure that the mass is given in kilograms and the velocity in meters per second. We think you used the wrong unit for one of these.

Next, you must remember to square the velocity, and also that the product mv^2 is to be divided by 2.

Please return to page 114. Make another choice after finding the correct answer.

YOUR ANSWER --- A

Two quantities are inversely proportional when one decreases as the other increases. We are trying to establish a definition of work in a physical sense. We have said that we would measure work in terms of the size of the job performed or the amount of fuel used to complete it.

It seems logical to connect the factors we have just considered in this manner:

1. To lift a single crate, a certain amount of fuel is needed.
2. To lift two crates, two cranes are required, thus calling for twice the applied force.
3. Two cranes, however, require twice the fuel of one.
4. So to get twice the force, we need twice the amount of fuel.
5. Since work is measured by the amount of fuel used, we would then expect two cranes to do twice the work of one crane by exerting twice the force at a given time.

Thus, the two quantities we are relating are work and force, and we see that as the force increases, the work increases. Is this an inverse relationship?

Please return to page 4 and select the alternative answer.

YOUR ANSWER --- D

That is not right. One of the answers is correct.

Go over your work. Remember, in solving K.E. = $\frac{1}{2}mv^2$, you must square the speed, multiply by the mass, and then divide by 2.

Please return to page 72. Choose the correct answer.

YOUR ANSWER --- C

This is not correct. You may determine the correct MKS energy unit in one of two ways.

(1) You may analyze the derivation closely and notice that since work is a measure of energy, the energy equation having been obtained directly from the definition of work, energy units must be exactly the same as work units.

(2) You may substitute units in K.E. = $\frac{1}{2}mv^2$ and thus determine the unit you derive for the entire quantity.

We are quite sure you did not follow either of these procedures. If you had, your result would not have had the newton as an answer.

Please return to page 132. Select a better answer.

YOUR ANSWER --- B

The example appears in item 1(d), not 1(c).

Please keep your notebook up-to-date and in usable shape.

Please return to page 138 and select another answer.

YOUR ANSWER --- A

This answer is incorrect.

You obtained this answer by multiplying the weight of the safe in pounds by the distance moved. This is a double error.

If you use the weight of the safe in this problem--and it should <u>not</u> be so used--it should be expressed in newtons rather than pounds.

However, in determining the work, the force that appears in W = Fd must be the one that is in the direction of the motion. The safe is moved horizontally but weight acts vertically.

Please return to page 142 and work the problem again.

CORRECT ANSWER: The dealer answered, "The brown stallion can pull the hay-wagon up the hill much faster than the black mare."

Here is a new thought! Suppose you had a load of books that were to be placed on a high storage shelf that could be reached only by climbing a ladder. For the sake of simplicity, we'll imagine each of the books to weigh exactly 5.0 nt, and that there are 20 of them altogether. Suppose further that they are to be lifted a distance of 4.0 meters. Since 5.0 nt represents a little more than one pound of weight, you might carry 10 books up in a single trip, completing the job in two trips. The work done would then be:

$$W = Fd = \text{number of trips} \times \text{weight} \times \text{height}$$
$$= 2(50 \text{ nt} \times 4.0 \text{ m}) = 2(200 \text{ j}) = \underline{400 \text{ j}}$$

Now, let's say that your little brother wants to do exactly the same job but that he can carry only 1 book at a time as he mounts the ladder. This means that he will have to make 20 trips up the ladder. The work he would do would be:

$$W = 20(5.0 \text{ nt} \times 4.0 \text{ m}) = \underline{400 \text{ j}}$$

Clearly, your little brother does exactly the same amount of work that you do in completing this job, but if an employer were looking for help in the form of a book-stacker, he would hire you rather than your brother. What physical quantity, not present heretofore in the concept of work and energy, has now appeared?

(33)

A A ladder.

B Time.

C Vertical distance.

D None of these.

YOUR ANSWER --- B

You are correct. $P = \frac{Fd}{t} = \frac{500 \text{ nt} \times 6.0 \text{ m}}{15 \text{ sec}} = 200 \text{ j/sec}$

To help you understand the relative magnitude of a joule per second, we'll discuss power in English units briefly, but will not work any problems involving them.

In the English system, force is measured in pounds (lb), distance in feet (ft), and time in seconds. Hence, the unit of work is the ft-lb, and the unit of power is the ft-lb/sec. Early in the development of the concepts involving power, horses were used to do the work of pumping water, grinding grain, hoisting stones, and so on, so that it was natural to choose a power unit involving these animals. At first, one horsepower was described as the rate at which a particular kind of animal, an English dray horse, could do the work. Obviously, such a definition is inadequate for anything but the roughest kind of calculations. Later, the definition of the horsepower was pinned down as:

$$1 \text{ horsepower} = 1 \text{ HP} = 550 \text{ ft-lb/sec}$$

Thus, the average horse might be expected to be able to do 550 ft-lb of work in 1 second.

To help you fix the relative size of the j/sec in your mind, we shall find the number of j/sec in 1 horsepower. The process of determination is given on the next page. It is not necessary for you to memorize this, but it is important for improving your facility with unit conversion, and for a valuable review. Therefore, follow each of the steps carefully to the conclusion.

Please go on to page 26.

We want to determine the number of joules per second in 1 horsepower, carrying the work to three significant figures.

(1) Write the definition of 1 j/sec: $1 \text{ j/sec} = \dfrac{1.00 \text{ nt} \times 1.00 \text{ m}}{1.00 \text{ sec}}$

(2) There are 3.28 ft/m and 4.45 nt/lb, or 1/4.45 lb/nt.

(3) Multiplying (1) by the conversions in (2):

$$1 \text{ j/sec} = \frac{1.00 \text{ nt} \times \dfrac{1}{4.45} \dfrac{\text{lb}}{\text{nt}} \times 1.00 \text{ m} \times 3.28 \text{ ft/m}}{1.00 \text{ sec}}$$

(4) Simplifying:

$$1 \text{ j/sec} = \frac{3.28}{4.45} \; \frac{\text{ft-lb}}{\text{sec}}$$

$$1 \text{ j/sec} = 0.738 \text{ ft-lb/sec}$$

(5) From (4) we see at once that 1 j = 0.738 ft-lb. This in itself is a valuable result. It shows that a joule is less than 1 ft-lb. So, there must be more joules than ft-lbs in a HP, that is,

$$1 \text{ ft-lb} = \frac{1}{0.738} \text{ j}$$

(6) We know that, by definition, 1 HP = 550 ft-lb/sec.

(7) Hence,

$$1 \text{ HP} = 550 \text{ ft-lb/sec} \times \frac{1}{0.738} \text{ j/ft-lb}$$

$$\text{or} \quad 1 \text{ HP} = \frac{550}{0.738} \; \frac{\text{j}}{\text{sec}} = 746 \text{ j/sec}$$

$$\text{Thus, } 1 \text{ j/sec} = \frac{1}{746} \text{ HP}$$

Please go on to page 27.

Here are the last two answers again:

$$1 \text{ HP} = 746 \text{ j/sec}$$

$$1 \text{ j/sec} = \frac{1}{746} \text{ HP}$$

This is the result we are seeking. You will find in your reading that another name for a joule per second is a watt. Hence, a watt is a unit of ______________.

(35)

A Work.

B Energy.

C Power.

D None of these.

YOUR ANSWER --- A

You obtained this answer by summing up the two individual momenta without regard for algebraic sign. Momentum is a vector quantity and signs must be taken into account in all arithmetic or algebraic manipulations.

Please return to page 127 and select a better answer.

This page has been inserted to maintain continuity of text. It is not intended to convey lesson information.

YOUR ANSWER --- B

If you write Newton's Second Law in any form, you cannot obtain an equality between F and m/a!

Refer to your notes if necessary for a review of the mathematical statement of the Second Law. You should remember, however, that acceleration is directly proportional to the unbalanced force, and inversely proportional to the mass of the body being accelerated.

Please return to page 91 and make a better selection.

YOUR ANSWER --- A

You are correct. This follows from the conservation principle. At the start of the swing, all the energy is P.E. At the end of the swing, it is again all P.E. Hence, if the energy of the system is to remain constant, mgh' must be equal to mgh.

Thus, an ideal pendulum would be a perfect energy converter. Each swing would see the bob rise to exactly the same height as before and, therefore, the pendulum would swing forever once started.

How to extract this energy to do useful work while keeping the pendulum going is a problem in perpetual motion. A pendulum clock has been devised, however, which uses very little external energy.

Please go on to page 32.

Before going on to the real world of physics where ideal conditions may be approached but never quite realized, here is one more application of the Principle of Conservation of Energy in connection with falling bodies. For simplicity, we shall use a numerical example.

A jet plane at an altitude of 9.00×10^3 m is carrying a 1,020 kg bomb. We want to find the kinetic energy of the bomb after it has been dropped and has fallen a distance of 6.00×10^3 m. (COPY THIS PROBLEM). You will note that the bomb has fallen 2/3 of the distance to the ground from its original altitude.

Now there is a difficult way to solve this problem, but there is also an easy one. Unfortunately, the difficult way is the obvious one. We'll go over this first. The problem suggests that we find K.E. Which equation will we apply?

(32)

A K.E. = mv^2

B K.E. = $\frac{1}{2}mv$

C Neither of these equations.

YOUR ANSWER --- A

This answer is incorrect.

Work the problem out again and determine the correct answer for yourself. Be sure your manipulations with exponents are correct.

Please return to page 137, then choose another answer that matches your revised one.

YOUR ANSWER --- A

How far does F_T in Figure 3 on page 99 cause the block to move? Remember that F_T is a reaction to W and that the block will not move vertically at all as long as the table is there.

All right. F_T causes no motion of the block; this fact is established.

Work is calculated from the expression W = Fd. Now, if F_T does not cause any vertical motion, there is no d over which it acts; hence for F_T, the distance d is zero.

Under these conditions, would you still say that F_T does the same amount of work as F?

Please return to page 99. Choose a better answer.

YOUR ANSWER --- B

You are correct. The proportionality between work and distance is almost self-evident in the relationship of the numbers chosen for the previous discussion.

Thus, we can write the proportionality this way:

$W = k'd$ where W = work, d = distance, and k' = a proportionality constant.

Well, let's review a bit. We have found so far that work is proportional to force ($W = kF$), and that work is also proportional to distance moved ($W = k'd$). Both of these are direct proportions.

In the next step we want to combine the two proportions. This is done by putting them together like this:

$W = k''Fd$ where k'' is some combination of the two

proportionality constants that appear in the separate statements above.

Here we can give the constant k'' a value of one (unity) by choosing our units correctly. If F is measured in newtons, and d is measured in meters, and if we assign a value of unity (without units) to k'', then what unit will we use for work?

(4)

A The newton-meter.

B The newton per meter.

C I don't recall how to do this.

YOUR ANSWER --- A

This is not correct.

A watt is the same as a joule per second. But if a joule is a unit of work, then a joule per second is a unit which measures the time rate of doing work, not work itself.

Please return to page 27 and select another answer.

YOUR ANSWER --- A

You are correct. To apply the relation: K.E. = $\frac{1}{2}mv^2$ we need to know the mass of the body and its final velocity as it reaches the ground.

All right. The mass is known: 5.00 kg. We know the distance that the block will fall: 3.00 m. We know the gravitational acceleration: 9.8 m/sec^2. What equation do you have that will enable you to find the final velocity of a body falling from rest, if the mass of the body, its acceleration, and the distance through which it falls are all known?

Write this equation, please. Don't go any further until it is written and you are certain that it is right.

Now turn to page 139.

YOUR ANSWER --- C

This is not a good answer. Although the acceleration of a freely falling body can be given as 980 cm/sec^2, this value is in CGS units.

This isn't what we want, is it?

Please remember the system we are working in.

Please return to page 128 and select the acceleration of free-fall in this system.

YOUR ANSWER --- C

Apparently you think that the total energy has been split down the middle, since half of 432 is 216. This is not so.

At $t = 3.00$ sec, the ball has reached the ground so that, with respect to ground as a reference zero level, the height of the ball is now zero.

At zero height, how much potential energy does the ball have?

Check your thinking. Return to page 76 and select a better answer.

YOUR ANSWER --- B

You are correct. If three cranes were used, the force applied simultaneously to the crates would be three times that of a single crane, the fuel consumption would be three times as great, and the work done, therefore, would be tripled.

So, if work is directly proportional to the applied force, we might write: $W = kF$ where W = work, F = unbalanced force, and k = the conventional constant of proportionality.

Now, what else determines how much work is done by the crane? Suppose the vertical distance from the dock to the ship's deck is 20 feet. If we measured the fuel consumed by the gasoline engine in lifting the crate a distance of 10 feet and found that it required 0.01 gallon of gasoline to do it, and then repeated the fuel consumption measure for a distance of 20 feet straight up, what do you think we would find?

(2)

A To lift a crate 20 ft would require no more gasoline than to lift it 10 ft.

B To lift a crate 20 ft would require 0.02 gal of gasoline.

C I don't understand.

YOUR ANSWER --- D

You are correct. The basic equation relating distance and time is: $d = \frac{1}{2}gt^2$ for a body that starts to fall from rest. When this is solved for t, you obtain the expression $t = \sqrt{2d/g}$.

All right, let's find the time required for the ball to fall to earth.

$$t = \sqrt{\frac{2 \times 44.1 \text{ m}}{9.80 \text{ m/sec}^2}} = \sqrt{9.00 \text{ sec}^2} = \underline{3.00} \ \underline{\text{sec}}$$

Now that we have the time needed for the ball to fall through 44.1 meters, we can proceed to part (b) of the problem.

At t = 0 sec, the ball has not yet started to fall. In short, its energy is entirely __________ energy. Write the missing word and then please turn to page 76.

YOUR ANSWER --- A

A ladder isn't a physical quantity or number!

We may not have worked any problems involving ladders before, but we certainly have dealt with bodies that have been lifted above the ground. The ladder is merely another means of lifting; it introduces no new ideas.

Please return to page 24 and choose a better answer.

YOUR ANSWER --- A

This is not true.

When a 120-lb boy climbs a vertical ladder, his muscles must exert a minimum of 120 lb of force in order to overcome his weight. If this muscular force, which is directed upward, causes him to move upward, then certainly work has been done because a force has caused motion.

Re-examine the problem after returning to page 87. Think carefully to choose the right answer.

YOUR ANSWER --- C

With reference to the zero level, what is the height of the ball as it passes through position (1) of Figure 9 on page 60? It is zero, isn't it? But if $h = 0$, then the potential energy, which is

$$P.E. = mgh$$

must also be zero.

If this is the case, how can the total energy of the bob comprise only P.E.?

Please return to page 62 and choose a better answer.

YOUR ANSWER --- C

This answer is not right.

You obtained it by multiplying the weight of the safe in newtons by the distance moved horizontally.

Remember that the force used in a work calculation must be acting in the direction of the motion. Weight acts vertically but this safe moved horizontally; hence you cannot use the weight of the safe as the force in $W = Fd$.

Please return to page 142 and select the right answer.

YOUR ANSWER --- B

Correct. Going back to our equations of uniformly accelerated motion, you should remember this one:

$$v = at \quad \text{or, for this case,} \quad v = gt$$

Hence, what is the speed of the ball at the end of 1.00 sec of free fall? Write the answer; then turn to page 72.

YOUR ANSWER --- C

You forgot to do something necessary for the solution of K.E. = $\frac{1}{2}mv^2$. What did you neglect to do?

Correct your work, return to page 72, and then choose the correct answer.

YOUR ANSWER --- C

Let's run through some of our preliminary points.

We are trying to develop a relationship between work and some combination of force and motion. In our introduction we used the word work as a measure of energy transfer, and said that it was evident that work could be measured by the amount of fuel used in doing a particular job.

Now our objective is to find out just what factors of force and motion govern the amount of work done or fuel used. We have already decided that work is proportional to force, but that there is something else that controls the amount of work done besides force.

When work is done, force produces motion. In our example of the crane hoisting crates, we are applying common sense to the question: "How much more fuel is used in lifting a given crate 20 ft compared to the amount used to lift the same crate 10 ft?" If we can determine this, we may then be able to show how work done is governed by the motion that occurs while the work is being accomplished.

Please return to page 40. Try another answer.

CORRECT ANSWER: Since the mass of the stone is 20 kg, then from

$$w = mg$$

we find the weight to be: $w = 20 \text{ kg} \times 9.8 \text{ m/sec}^2 = \underline{196} \ \underline{\text{nt}}.$

So we have:

$$h = \frac{1{,}440 \text{ j}}{196 \text{ nt}}$$

$$h = \underline{7.3} \ \underline{\text{meters}}$$

Thus, when a 20-kg stone is dropped from a height of 7.3 meters, it acquires 1,440 joules of K.E. when it reaches the ground.

When an object is at rest at some height above ground level, whatever energy it possesses is potential in nature; it has no kinetic energy because it is not moving. We know, too, that if the object is allowed to fall to ground level its energy upon impact with the ground will be <u>all</u> kinetic. Its potential energy will now be zero, since all the initial P.E. has been converted to K.E.

Please go on to page 50.

Here is another question: Given a specific P.E. for a body raised to a height, can we calculate how much of this P.E. has been changed to K.E. at any instant--part of the way down--in its fall?

COPY THE FOLLOWING PROBLEM (It will be more convenient to work this one out to three significant figures.): A 1.00 kg ball is dropped under ideal conditions from a height of 44.1 meters.

(a) Determine the time required for it to reach the ground.
(b) Calculate its P.E. and K.E. for
  (1) $t = 0$ sec
  (2) $t = 1.00$ sec
  (3) $t = 3.00$ sec

Now turn to page 51.

This problem is not quite as formidable as it first appears. From your copy of the problem, list the known quantities:

$$m = 1.00 \text{ kg}$$
$$d \text{ or } h = 44.1 \text{ m}$$
$$g = 9.80 \text{ m/sec}^2$$

Part (a) of the problem calls for the determination of the time required for the ball to reach the ground. This is a straightforward question in uniformly accelerated motion as applied to bodies in free fall.

Choose the equation from those listed below which will permit you to find the time of fall directly from the data given.

(23)

A $t = \frac{d}{v}$

B $t = \frac{2g}{d}$

C $t = \frac{2d}{g}$

D $t = \sqrt{\frac{2d}{g}}$

YOUR ANSWER --- B

We showed that W = k"Fd.

In this expression, the portion "Fd" is a <u>product</u>. Since "per" signifies a fraction bar, the unit for work could be a newton per meter only if the proportion involved a quotient. Since there is no quotient expressed or implied, there can be no "per" in the unit.

Please return to page 35. The answer should be clear now.

YOUR ANSWER --- A

Despite the unfamiliarity of the unit used to express work in this answer, you chose it. You must have had a reason for doing so. Going back to the definition for power:

$$P = W/t$$

and since we want the work done, we can solve the equation for W:

$$W = Pt$$

The power is 500 watts and the time is 1 minute, so

$$W = 500 \text{ w} \times 1 \text{ min} = \underline{500 \text{ watt-min}}$$

But this isn't the answer you selected, is it? What's wrong? Compare with the answer above, as you selected it.

Go back to the original question on page 121 and work the problem again.

YOUR ANSWER --- A

You are perfectly correct.

The kinetic energy of the block as it returns to the ground is:

$$K.E. = \frac{1}{2}mv^2 = \frac{1}{2} \times 5.00 \text{ kg} \times 58.8 \text{ m}^2/\text{sec}^2 = \underline{147 \text{ joules}}$$

The kinetic energy of the falling block when it reaches ground level is exactly the same as the work originally put into the job of raising the block. From this we must conclude that 147 joules were stored in the block while it rested on the shelf, and that all this energy was converted to K.E. at the end of its fall.

NOTEBOOK ENTRY
Lesson 12

2. Potential Energy

(a) Potential energy is the energy possessed by a body because of its position or distortion.

(b) Under ideal conditions, P.E. is equal to the work required to bring the body to that position, or to cause the distortion.

(c) For potential energy of raised position (against gravity), the work done to bring it to that position is $W = Fd$. But the force in this case is the same as the weight w of the body, and the distance raised is to be called the height h. Hence, we may express P.E. of position as P.E. $= wh$.

(d) In the MKS system, w is in newtons, h is in meters, and P.E., therefore, is in joules.

Please turn to page 184 in the blue appendix.

In the notebook entry, we mentioned the potential energy of distortion. Let's explore the matter further.

A body can store up potential energy if it is raised to some height above the ground. We say the body has potential energy because, if its support is removed, it will fall and convert all the P.E. it had while at rest to K.E. as it reaches the ground. For bodies that have potential energy as a result of their position, we shall call ground level zero height.

The most common way to tell if an object has potential energy is to note whether or not this object will have kinetic energy when released.

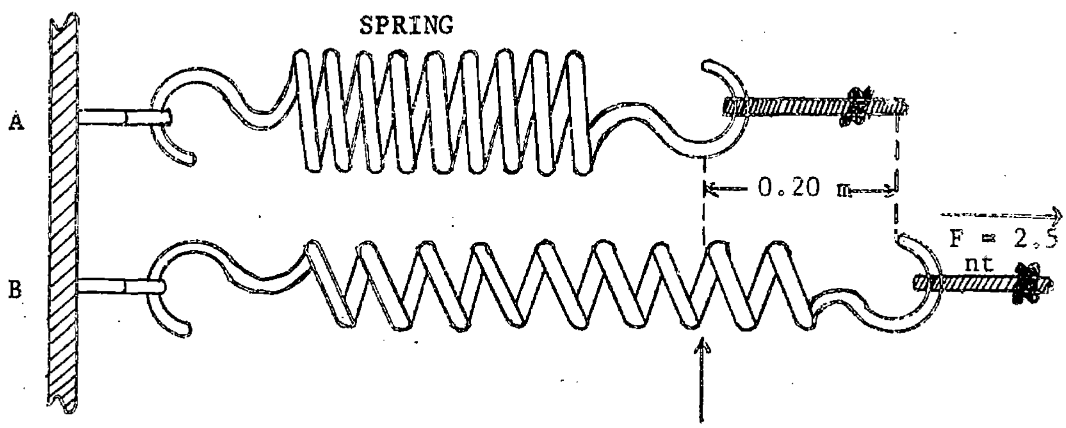

Figure 8

Referring to Figure 8, we see an unstretched spring in A (ignore gravitational effects), and the same spring in the stretched state in B. To stretch it, an average force of 2.5 nt was applied, causing the spring to lengthen by 0.20 meters. The spring has been distorted; its form in B is different from its form in its relaxed state in A. If the spring is released, that is, if the force is removed, the end of it will leap back toward the left causing the mass of its turns to move. We conclude, then, that the stretched spring possessed potential energy which is converted to kinetic energy when the end is released.

How much P.E. did the spring possess in its stretched state? Write your answer; then turn to page 114.

YOUR ANSWER --- B

You are correct. This answer is based on plain logic. If the engine can raise a crate 10 ft with 0.01 gal of gasoline, then it is reasonable to expect it would use twice as much gasoline to raise the crate twice the distance. Similarly, if the same engine were called upon to lift the same crate through 100 ft, we would expect that the gasoline consumed would be 100/10 x 0.01 gal or 0.1 gal.

Again relating the work done to the fuel used, we see that the engine must do twice as much work to raise a crate through twice the distance, three times as much work for three times the distance, and ten times as much work for ten times the distance.

What relationship does this suggest?

(3)

A Work is equal to the distance moved.

B Work is directly proportional to the distance.

C As the distance is increased, the work done increases.

YOUR ANSWER --- D

This is not the right answer. One of the answers is correct.

A watt is the same as a joule per second. And a joule is a unit of work. What kind of a unit, then, does the joule per second measure?

Please return to page 27 and make another choice.

CORRECT ANSWER: When $t = 1.00$ sec, the body falls <u>4.90</u> meters.

That is:

$$d = \frac{gt^2}{2} = \frac{9.80 \text{ m/sec}^2 \times (1.00 \text{ sec})^2}{2} = \underline{4.90 \text{ m}}$$

The original height of the ball was 44.1 meters, so the new height at the end of 1.00 sec is:

$$44.1 \text{ m} - 4.90 \text{ m} = \underline{39.2 \text{ m}}$$

Thus, we have 1.00-kg ball (weight = 9.80 nt) at a height above ground of 39.2 m.

What is the potential energy of the ball in this position with reference to ground? Write out the solution and the answer; then turn to page 144 to check your work.

YOUR ANSWER --- C

You are correct. The units of work are given as the newton-meter or joule.

In the discussion just completed, we have established a very useful basic concept: The conservation of energy in ideal situations. Next, we shall apply this concept to the analysis of the motion of a simple pendulum.

For this application please turn to page 60.

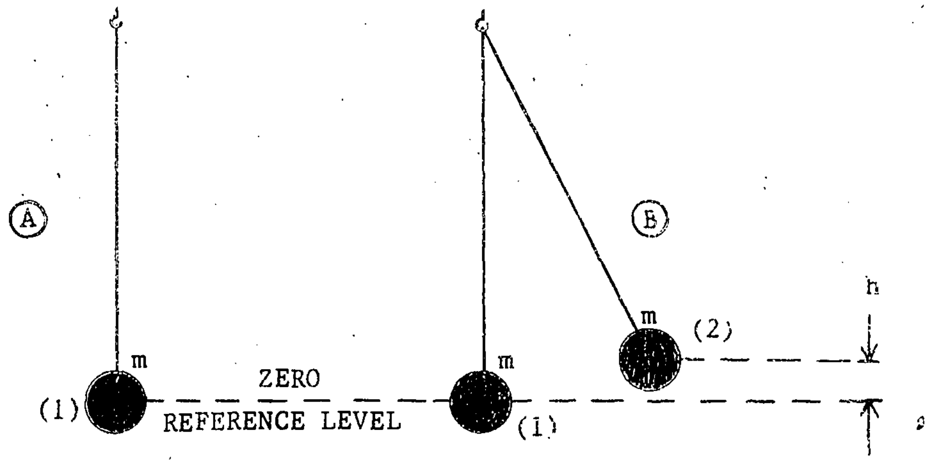

Figure 9

When a ball (called a pendulum bob) is hung from a support by means of a string, it hangs straight down forming what is known as a plumb line. The center of gravity of the bob may be assumed to be at the geometric center of the sphere. In position (1), Figure 9A, the center of gravity of the bob is taken as zero reference level from which all heights or depths are measured. The bob has a mass m.

When a force is exerted sidewise on the bob, it can be displaced to position 2, as in Figure 9B, with the string still taut. Since the horizontal component of gravity is negligible for small displacements of the bob, we assume the work required to move the bob horizontally is zero. But work is involved in moving the bob to position 2, because it has been raised vertically through distance h. How much work was done in moving it from (1) to (2)?. Remember, $w = m \times g$.

(29)

A The work done was equal to $m \times h$.

B The work done was equal to $m \times g \times h$.

YOUR ANSWER --- C

You took the right road but stumbled over a detail.

The equation for kinetic energy is $\frac{1}{2}mv^2$ <u>not</u> just mv^2.

This should give you a hint to enable you to locate your mistake. Do so, then return to page 123 and select the right response.

YOUR ANSWER --- B

You are correct. The force that lifts the mass is the vertical component of whatever force is applied to do the job. But the vertical component of this force must be equal to the weight of the bob, exerted in an upward direction. Then, since $w = mg$, the work done is equivalent to mgh.

Now picture the bob held in position (2) of Figure 9 on page 60. It is motionless, hence its kinetic energy is zero. Thus, all the work done on the bob, representing the total energy of the system, now resides in it in the form of potential energy. We can express it this way:

$$W = \text{total energy} = K.E. + P.E. = 0 + P.E. = \underline{\text{just } P.E.}$$

If the ball is now released, it will gather speed as it moves to the left. It will then pass through position (1) some time during this motion.

At the instant the ball passes through position (1), which of the following statements would correctly describe the energy distribution?

(30)

A The total energy of the bob comprises only K.E.

B The total energy of the bob comprises some K.E. and some P.E.

C The total energy of the bob comprises only P.E.

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This page has been inserted to maintain continuity of text. It is not intended to convey lesson information.

YOUR ANSWER --- C

Although this statement is true, it is incomplete. The figures given should enable you to state a relationship that is more meaningful.

Certainly, the work increases as the distance increases. But is it true that the work triples as the distance doubles, or that the work rises to 100 times its former value if the distance is increased 10 times? Of course not! Yet in both these cases, the work increases as the distance increases.

So, you see that your answer is too qualitative; it does not contain all the information that can be derived from the discussion.

Therefore, please return to page 56 and find the answer that does have this information.

YOUR ANSWER --- C

There is no such equation!

Although this expression does relate time and distance--and this is the relationship you would need to determine the time of fall of the ball over a distance of 44.1 meters--it does not relate them properly.

You may need to go back over the appropriate equations in your notes and review them before you return to page 51 and select another answer.

YOUR ANSWER --- C

If you have the right answer for the K.E. of the block as it returns to ground level, the appropriate conclusion ought to be apparent immediately. Perhaps you made an error in arithmetic. Once you get the right result for the K.E., you should reach a conclusion that can be generalized. Let's review the points made thus far:

(1) 147 joules of work did the job of raising the 5.00-kg block a distance of 3.00 meters.

(2) We decided that the K.E. of the block on the shelf was zero because it was not in motion, and its velocity was zero.

(3) However, having done 147 joules of work on the block, we felt that <u>we must have added energy to it</u>. Since this energy is evidently not kinetic, then it must be another kind of energy.

(4) We concluded, therefore, that the energy (147 joules) is stored because of the block's raised position. We called this <u>potential energy</u>.

(5) To test this theory, we computed its K.E. when the block fell to its original position. Finally, we must compare this K.E. with the original work done in the P.E. "storage" process.

Please return to page 139 and select another answer.

YOUR ANSWER --- B

This expression is not valid. We have never derived nor used anything like it.

Although this expression does relate time and distance--and this is the relationship you need to determine the time of fall or the ball over a distance of 44.1 meters--it does not relate them properly.

You may need to go back over the appropriate equations in your notes and review them. Then please return to page 51 and select another answer.

YOUR ANSWER --- B

Not directly.

The equation $d = \frac{1}{2}at^2$ gives the relationship between time, acceleration, and distance. It does not relate velocity to the other quantities.

Please return to page 124 and make a selection that fits the question.

YOUR ANSWER --- C

You've erred somewhere in your calculation.

One of the answers is correct. Check your work; then please return to page 143. You should be able to pick the right answer.

YOUR ANSWER --- B

You are absolutely correct. Since you know mass m and velocity v, you can make direct substitutions into the equation:

$$K.E. = \frac{1}{2}mv^2$$

Remember, we want to find the height from which the stone was dropped. Let's compute the kinetic energy at ground level:

$$K.E. = \frac{mv^2}{2} = \frac{20 \text{ kg} \times (12 \text{ m/sec})^2}{2}$$

$$K.E. = \underline{1{,}440} \ \underline{\text{joules}}$$

Assuming ideal conditions, the potential energy of the stone at the height from which it fell must also be 1,440 joules, since all the P.E. was converted into K.E. by the time the stone reached the ground.

$$P.E. = 1{,}440 \text{ joules}$$

but P.E. = wh, so

$$wh = 1{,}440 \text{ joules}$$

$$\text{and} \quad h = \frac{1{,}440 \text{ joules}}{w}$$

The mass of the stone is 20 kg. What is its weight? <u>Write your answer.</u>

Now turn to page 49.

CORRECT ANSWER: At the end of 1.00 sec of free fall, the speed of the ball is 9.80 m/sec. That is,

$$v = gt = 9.80 \text{ m/sec}^2 \times 1.00 \text{ sec} = 9.80 \text{ m/sec}$$

We want to calculate the K.E. of the ball, then, when its speed is 9.80 m/sec. What do you get for the kinetic energy at this speed?

(26)

A 96.0 joules.

B 48.0 joules.

C 4.9 joules.

D None of these answers.

YOUR ANSWER --- B

What's wrong with this answer? It is correct. From $W = k''Fd$, we obtain $W = Fd$ when we make $k'' = 1$. Then substituting for F and d, we have:

$$W = 3.6 \text{ nt} \times 0.70 \text{ m}$$
$$W = 2.52 \text{ nt-m}$$

However, since a newton-meter is a joule, we can express this answer as W = 2.52 joules. And since we are working with only two significant figures, the final result is best expressed as

$$W = 2.5 \text{ joules.}$$

One of the answer choices, however, is wrong on two counts. Please return to page 119; find the answer we mean.

YOUR ANSWER --- D

At the start of the free-fall process, the total energy of the ball was all potential--432 joules. If you say that on reaching the ground, the P.E. of the ball is still 432 j and its K.E. is also 432 j, how do you account for the fact that the total energy of the ball would then be 432 j + 432 j = 864 j? The only work done on the ball was that involved in the raising process, 432 j. You know that work must be done to give something energy. You can't add another 432 j to the energy without accounting for it.

Furthermore, you know that potential energy of position is the product of the weight and height. But, at ground level, the height of the ball above the ground is zero; hence its P.E. = 2 x 0 = 0.

Please return to page 76 and select a better answer.

CORRECT ANSWER: Force F may be considered to be made up of a horizontal and a vertical component.

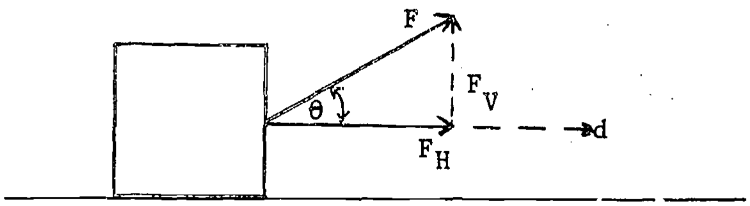

Figure 5

Figure 5 illustrates the resolution of force F into its two components, F_H and F_V. Ignoring F, now we can talk of the effects of the components. As we saw before, a vertical force that causes no vertical motion does absolutely no work. This means, of course, that F_V may be ignored, too, as long as we confine our discussion to the forces that do work in our example.

On the other hand, the horizontal component of F (F_H) is the force which causes the actual, observed motion resulting in the displacement d. Thus, only F_H does work along the horizontal line as the block moves over the distance d.

Now, you should be able to write the equation for the work done in the situation shown in Figure 5. Which of the following correctly describes it?

(7)

A $W = Fd$

B $W = F_V d$

C $W = F_H d$

D $W = F_H F_V d$

CORRECT ANSWER: At $t = 0$ sec, before the ball starts to fall, its energy is entirely potential.

The body is not in motion, so it has zero kinetic energy. To find its total energy then at $t = 0$ sec, we must determine its potential energy.

$$\begin{aligned} \text{P.E.} &= wh \\ \text{but since } w &= mg \\ \text{then P.E.} &= mgh \end{aligned}$$

and substituting, we can write:

$$\text{P.E.} = 1.00 \text{ kg} \times 9.80 \text{ m/sec}^2 \times 44.1 \text{ m}$$
$$\text{P.E.} = \underline{432 \text{ joules}}$$

Thus, in answering (1) of part (a) of the problem we would say that:

the ball's P.E. at $t = 0$ is 432 joules
the ball's K.E. at $t = 0$ is zero.

Now, without further calculation you should be able to tell us the P.E. and K.E. of the ball at $t = 3.00$ sec. (Remember that we calculated the time required for the ball to come to ground level as 3.00 sec.)

Don't hurry. Take the time you need to think this out. Then select an answer from those listed below:

At $t = 3.00$ sec, the ball has a

(24)

A P.E. of zero and K.E. of 432 j.

B P.E. of zero and K.E. of 288 j.

C P.E. of 216 j and K.E. of 216 j.

D P.E. of 432 j and K.E. of 432 j.

YOUR ANSWER --- A

Incorrect!

We know the mass of the ball. It is a constant value of 1.00 kg and is not affected by the motion of the ball in free fall.

Please return to page 144 and choose the alternative answer.

YOUR ANSWER --- A

The product m x h is a product of a <u>mass</u> and a distance.

You know that work is a product of a force and a distance. Then the product m x h can not express work.

Please return to page 60 and select the other answer.

YOUR ANSWER --- C

We'll refresh your memory.

Let's go back to Newton's Second Law. Your notes will show that we had a similar proportion involving force, mass, and acceleration which could be put into the form $F = k''ma$.

In deciding upon the unit to be used for force F, we allowed the k" to be dimensionless with a value of unity and then wrote:

$$F = \underset{\substack{\uparrow \\ k''}}{(1)} \times \underset{\substack{\uparrow \\ m}}{kg} \times \underbrace{m/sec^2}_{a}$$

Then we said that the unit for force must be the kilogram-meter per second squared, or $kg\text{-}m/sec^2$.

Thus, in forming the unit for the derived quantity (force in the case of the Second Law), we merely perform the operations dictated by the defining equation, multiplying or dividing or both, depending on the instructions in the equation.

In this case, sec^2 appears in the denominator of the force unit because it is in the denominator of the unit for acceleration.

Perform exactly the same operation with the expression:

$$W = k''Fd$$

Now return to the original question on page 35 and select the right answer.

YOUR ANSWER --- A

Correct.

When it is at position (1) of Figure 9 on page 60, whether it is in motion or not, the height of the bob is considered to be zero since this is the zero reference level. Since mgh newtons of work were done on the bob to raise it to height h, it must have been given mgh newtons of total energy At position (1), we see that its P.E. is zero; hence the total energy must be all K.E., by the Principle of Conservation of Energy. If the bob is moving with speed v at position (2), then the total energy of the system is

$$\text{Total Energy} = \text{K.E.} + \text{P.E.} = \text{K.E.} + 0 = \tfrac{1}{2}mv^2$$

Now turn to page 81.

Now refer to Figure 10.

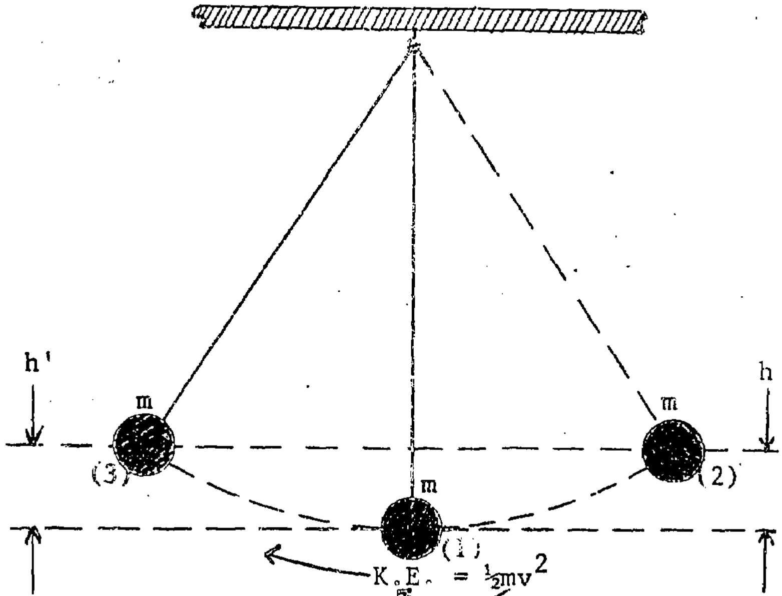

Figure 10

The bob passes through (1) and, because it has kinetic energy, it continues to move toward the left, rising to height h' at position (3). Here it stops moving, before reversing direction on its next swing. At position (3), the bob again has zero K.E., and the total energy of the system is all P.E. In this case, the P.E. = mgh'. Select the only true statement.

(31)

A The magnitude of mgh' is exactly the same as mgh.

B The magnitude of mgh' is smaller than that of mgh.

C The magnitude of mgh' is greater than that of mgh.

YOUR ANSWER --- A

You are quite correct.

So far we have:

$$W = mad$$

and also

$$v^2 = 2ad$$

Suppose we solve this last equation for a. This gives us:

$$a = \frac{v^2}{2d}$$

Thus, $v^2/2d$ is the equivalent of a and may be substituted for it in the expression W = mad.

We would like to make the substitution and then simplify the resulting expression as much as possible. Write your answer, then see which of the following is a true statement.

(12)

A $W = \frac{mv^2}{2d}$

B $W = mv^2$

C Neither of these answers is right.

We should like to close this lesson by describing a simple experiment in which the conservation principles for both momentum and energy, help us to appreciate the importance of remembering which quantity is a vector and which a scalar.

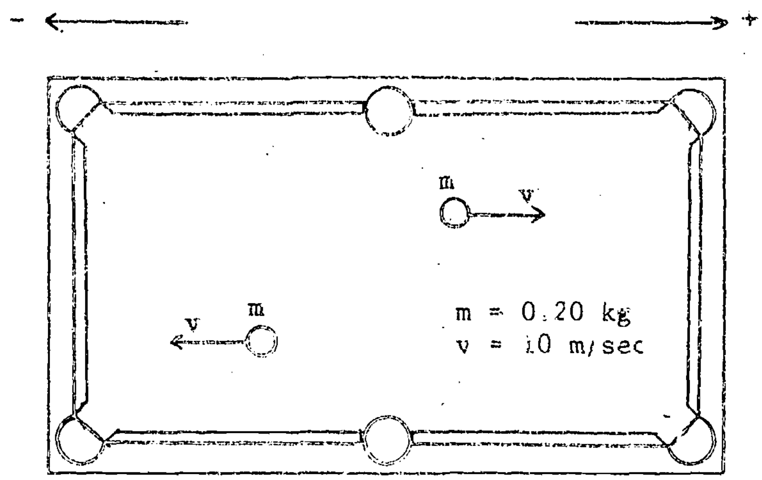

Figure 11

In Figure 11, we see a billiard table from above. Two billiard balls of equal mass m are moving with equal uniform velocities in opposite directions.

Bearing in mind that energy is a scalar quantity, we are not concerned with the directions of the two motions in answering the question: What is the total kinetic energy of the <u>system</u>? The system includes both balls and the table. Clearly, if directions are not to be taken into account, then the total kinetic energy of the system is the sum of the two individual energies, or

$$\text{Total K.E.} = \tfrac{1}{2}mv^2 + \tfrac{1}{2}mv^2 = mv^2$$

If each m = 0.20 kg and each v = 10 m/sec, then the total kinetic energy is 20 joules. Despite the fact that the balls roll in opposite directions, each one could do 10 joules of work if called upon to do so.

Please turn to page 127 to continue.

YOUR ANSWER --- C

This is not true. You do have enough data to answer this question.

To determine the kinetic energy of any body, what do you have to know? Since K.E. = $\frac{1}{2}mv^2$ you need information relative to the mass of the body and its velocity at the time the kinetic energy is to be calculated. Well, aren't both of these known? Sure, they are! So you do have enough data to find the K.E. of the block after it comes to rest on the shelf.

Please return to page 150 and select an answer that matches the information you have.

YOUR ANSWER --- A

No.

Check your notes for the correct equation, although this should no longer be necessary. Important relationships should become part of your physics "vocabulary" as quickly as possible.

Please return to page 32. Check your notes before choosing your next answer.

YOUR ANSWER --- C

You are correct. The work in this case is the product of the horizontal component F_H and the displacement d.

Let us now state a firm and rigorous definition of work as a notebook entry.

NOTEBOOK ENTRY
Lesson 12

Work and Kinetic Energy

1. Definition of Work

(a) Work is defined as the product of the component of force along the direction of motion and the distance moved as a result of the action of this component.

(b) The equation for work may be written: $W = Fd$ where F is the component of the force in the direction of motion and d is the displacement or distance moved.

(c) Work is measured in newton-meters or joules in the MKS system.

(d) Illustrative example: A force of 18 nt acts at an angle θ on a block of wood on a table. The angle is such that the force may be resolved into a horizontal component of 16 nt and a vertical component of 9 nt. If the block moves 4 m along the horizontal table, how much work was done?

Solution: Only the horizontal component of the applied force is involved in the work; hence $W = Fd = 16$ nt x 4 m = 64 nt-m = 64 joules.

Please turn to page 182 in the blue appendix.

Here's another simple problem, involving the principles of work: A word of caution is in order here. Watch the units very carefully. They can always be combined by performing the operations dictated by the defining equation.

A boy weighing 120 lb climbs a vertical ladder 13 ft high. How much work does he do?

(8)

A He does no work.

B 1,600 joules

C 1,600 nt-mt

D 1,600 ft-lbs

YOUR ANSWER --- A

You are correct. The kilowatt-hour (kw-hr) has exactly the same form as the watt-second (w-sec). It is a product of power and time or:

$$\text{kw-hr} = P \times t = \frac{\text{energy}}{\text{time}} \times \text{time} = \text{energy or work}$$

The power equation, $P = Fd/t$, is also useful in a slightly different type of computation. For example, in the problem below, how do we get <u>speed</u> into the picture?

An electric motor is rated to deliver 10.0 kw of power. At what speed in meters per minute (m/min) can this motor raise a load that has a mass of 2.[illegible]5 x 10^2 kg?

We have been using the simplest representation for work in the numerator of the right side of the power equation. That is, when we write <u>Fd</u>, we mean that an unbalanced force F has caused a displacement of a body in the direction that the force acts. Normally, we would indicate a displacement as Δd since it does involve a <u>change</u> of position. If we do that, then the power equation becomes:

$$P = \frac{F\Delta d}{\Delta t}$$

which can be rewritten this way:

$$P = F \times \frac{\Delta d}{\Delta t}$$

In this equation, with what could you replace $\frac{\Delta d}{\Delta t}$?

(39)

A Neither of these answers is correct.

B Acceleration of the body on which the force acts.

C Speed of the body on which the force acts

CORRECT SOLUTION:

Given: $P = 10.0 \text{ kw} = 10^4 \text{ watts} = 10^4 \text{ j/sec}$
$m = 2.75 \times 10^4 \text{ kg}$

Since $w = mg$, then $w = 2.75 \times 10^4 \text{ kg} \times 9.8 \text{ m/sec}^2$
$w = 27.0 \times 10^4 \text{ nt} = 2.70 \times 10^5 \text{ nt}$

So $F = 2.70 \times 10^5 \text{ nt}$
$P = Fv$, hence $v = P/F$

Therefore:

$$v = \frac{10^4 \text{ j/sec}}{2.70 \times 10^5 \text{ nt}}$$

Now, dividing j/sec by nt gives us m/sec, because

$$\frac{\frac{j}{sec}}{nt} = \frac{\frac{nt\text{-}m}{sec}}{nt} = \frac{m}{sec}$$ Thus $v = 0.037$ m/sec.

To obtain the answer in meters per minute, we multiply by 60 sec/min and get:

$\underline{v = 2.22 \text{ m/min}}$ (final answer)

NOTEBOOK ENTRY
Lesson 12

(Item 5)

(h) Power and speed are related by the expression: $P = Fv$ where P = power in watts or j/sec, F = unbalanced force in newtons, and v = speed in meters per second.

(i) Copy the problem just completed as a sample for this entry.

Please go on to page 90.

Did you find the right answer for the last problem? If not, be more careful with this next one.

Energy is expended at the rate of 5.0×10^3 joule/second in causing a 3.2×10^3 kg block to move horizontally against friction on the floor at 2.0 m/sec. Find the retarding force of friction.

Write out your solution carefully; then turn to page 125.

initial velocity = 0

If work is a measure of energy transferred, then we should be able to determine the energy of the moving block by calculating the work (assuming that all the work done appears in the form of energy of motion.)

Obviously, the work done may be obtained from $W = Fd$, since the force is constant and in the direction of the motion. So $W = Fd$.

We should now like to find an expression for the energy in terms of the motion of the body. For clarity, consider this situation: if the mass m were to come sliding past you at a velocity v (as in Figure 6 on page 117), you could be sure that work had been done on the body during some past interval in order to overcome its inertia and accelerate it from rest to the velocity v, even though you had absolutely no information concerning the force that was used, or the distance over which the force acted. In other words, the energy of the mass m moving with velocity v should be calculable simply from a knowledge of the magnitude of m and v without reference to the original force F or distance d. To do this, we must convert $W = Fd$ into another equation containing m and v, rather than F and d. As a start, we could replace F with its equivalent using Newton's Second Law of Motion. What could replace F?

(10)

A $\frac{a}{m}$

B $\frac{m}{a}$

C ma

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YOUR ANSWER --- B

This answer neglects the difference between weight and mass.

Work is a force in the direction of motion times the distance moved. If work is a product of force and distance, then it cannot be a product of mass and distance. Force is measured in newtons. You multiplied the mass of the block (5.00 kg) by the distance vertically (3.00 m) and obtained an answer of 15.0 joules.

To find the work in this case, you must multiply the necessary force to lift the block by the distance.

Please think it over. Then return to page 170 and make a better selection.

YOUR ANSWER --- D

A newton is a unit of force, not work! If the watt-second is really a work unit it cannot be the same as a force unit, can it?

If you will remember that a watt and a joule per second are identical units, you should have no difficulty in choosing the right answer.

Please return to page 140 and make another selection.

YOUR ANSWER --- C

Not directly.

The equation v = at gives the relationship between final velocity, acceleration, and time. It does not relate distance to the other quantities.

Please return to page 124. Make the selection that meets the requirements of the question.

YOUR ANSWER --- B

The watt is not a unit of energy.

A watt is a joule per second; a joule is a unit of work and we have seen that work and energy are measured in the same units; hence, the joule is also a unit of energy. Then, a joule per second, and therefore a watt, must be a unit for measuring the time rate of energy usage, not energy itself.

Please return to page 27 and select another answer.

YOUR ANSWER --- C

You are quite correct. There are two errors in this answer. Most important is the unit error: The product of force and distance cannot be expressed as newtons per meter as we have explained before. The correct unit is the nt-m, or the joule. Also, since the problem is given to two significant figures, the answer should not have three significant figures.

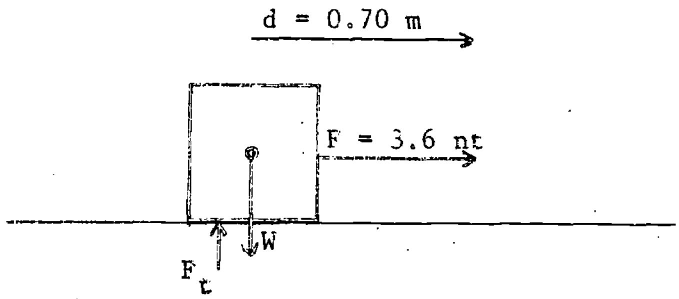


Figure 3

You may have noted that Figure 3 has the addition of two forces besides the unbalanced horizontal force of 3.6 nt. This is a real block and it has a definite amount of weight, W. But, since it doesn't fall through the table, it is held in static equilibrium by the reaction force exerted upward by the table, F_T. We might say that the block is acted on by 2 forces, F and F_T, while it acts upon the table with the force W, its own weight.

Now, here's our question. F acts on the block and does work to the extent of 2.5 joules. F_T also acts on the block. How much work does it do?

(6)

A The same as F, that is, 2.5 joules.

B No work at all.

C I don't know.

YOUR ANSWER --- D

No. This is defined in item 2(a).

You have the wrong item. If you're going to make progress, you have to keep your notes neat and in order.

Please return to page 138 and choose again.

YOUR ANSWER --- B

No, that's incorrect.

You forgot that, in kinetic energy, we are dealing with the <u>square</u> of the speed.

Work the problem once more, then return to page 137 please, and choose an answer that conforms with your revised work.

YOUR ANSWER --- C

The prefix "kilo" means "1,000 times." Thus, a kilowatt is the same as 1,000 watts. When we write "kilowatt-hour", we state that we are multiplying power times time.

"Power per unit time," however, states that power is being divided by time. Some other familiar examples of this are:

acceleration = change of velocity per unit time = v/t

and

density = mass per unit volume = m/v

Note the division sign in each of these examples, representing the word "per."

Hence, the kilowatt-hour (kw-hr) cannot be defined as power per unit time since it is a product, not a quotient.

Please return to page 145. Choose the right answer this time.

YOUR ANSWER --- D

Oh, come now!

We haven't work with English units in any of our lessons. Why should we turn to them now?

Please return to page 128. Stay in the preferred metric system.

YOUR ANSWER --- D

Work is the product of a force and a distance. This answer shows two forces and a distance in the product. This could hardly fit the definition of work, could it? How much does the component of force at right angles to the direction of motion contribute to the work expended?

Please return to page 75; then pick a better answer.

YOUR ANSWER --- B

No.

Acceleration is defined as the rate of change of velocity with respect to time, or $a = \Delta v/\Delta t$.

Here we are dealing with a rate of change of displacement with respect to time. This is <u>not</u> acceleration.

Please return to page 88 and make a better answer choice.

YOUR ANSWER --- B

We're not planning to <u>push</u> the block down; we're just going to let it fall by pulling the shelf out of way.

In that case its initial velocity would be zero, wouldn't it? There's nothing to determine in this respect then.

Please return to page 157. You should be able to choose the right answer.

YOUR ANSWER --- A

You omitted one step in the solution of K.E. = $\frac{1}{2}mv^2$. Which step is it?

Correct your work, return to page 72, and then select the right answer.

YOUR ANSWER --- A

We disagree.

So far, our definition of work states that $\vec{W} = Fd$, since the proportionality constant has dropped out. Substituting in this simple equation:

$$W = Fd$$
$$W = 3.6 \text{ nt} \times 0.70 \text{ m}$$
$$W = 2.52 \text{ nt-m}$$

And since we are working to two significant figures, the answer should be given as $W = 2.5$ nt-m.

There is one answer, however, that is definitely incorrect on two counts. Return to page 119, find this answer, and indicate your selection by picking the associated letter choice.

YOUR ANSWER --- B

This choice of answer indicates that you must have obtained an incorrect result for your calculation.

Perhaps the error was one of arithmetic. Before going through the work again, let's briefly check the points made thus far.

(1) We have shown that 147 joules of work were done in raising the 5.00-kg block through a distance of 3.00 meters.

(2) We decided that the block could not have any kinetic energy after coming to rest on the shelf, simply because it was not in motion and its velocity was zero.

(3) But, having done 147 joules of work on the block, we felt that we must have added energy to it. If this added energy is not K.E., then it must take some other form.

(4) We then said that the energy was stored in the block in the form of so-called potential energy.

(5) To test this theory, we then computed its K.E. when the block fell to its original position. Finally, we shall want to compare this K.E. with the original work done in the P.E. "storage" process.

Please return to page 139 and select another answer.

YOUR ANSWER --- A

This expression is applicable _only_ to motion with uniform velocity. It may not be applied to uniformly accelerated motion, such as that of a ball in free fall.

You are looking for an equation which relates _time_ and _distance_, since you know the distance of fall and want to find the time required.

If necessary, review the appropriate equations in your notebook. Then return to page 51 and make another choice.

YOUR ANSWER --- A

You apparently missed the point. Observe in Figure 5 on page 75 that the force F acts at an angle to the horizontal plane (θ), but that the block moves along the horizontal line in covering the distance d. Our latest tentative definition of work requires that, if work is to be done, the motion must be in the direction of the force. Since the motion and the force are not in the same direction, then the work cannot be the product of F and d.

Read over the text again, particularly the part about the resolution of F. Then select your answer carefully.

Please return to page 75 and try again.

YOUR ANSWER --- B

Let's analyze your answer carefully. If the magnitude of mgh' was actually smaller than that of mgh, this would mean that the potential energy at (3) of Figure 10 on page 81 was less than the potential energy at (2). Now, at <u>both</u> positions, the kinetic energy is zero; hence the P.E. <u>is</u> the total energy of the system.

Do you see the implication? When you select this answer, you are saying that some energy vanished altogether in the transition of the first swing of the pendulum. Working under ideal conditions as we are, this is quite impossible according to the Principle of Conservation of Energy. All the P.E. of the raised bob in position (2) must have become transformed into K.E. in position (1) which, in turn, reverted to P.E. when the bob reached position (3).

So--how could the P.E. in position (3) be smaller than that of position (2)?

Please return to page 81. You should be able to select the right answer without difficulty now.

YOUR ANSWER --- D

This is not true.

One of the given answers is quite correct. The thing to do is to let kinetic energy equal the work performed.

Try again.

Please return to page 123.

CORRECT ANSWER: The potential energy of the spring was 0.50 j.

This answer results from these considerations:

(1) The work done on the spring in stretching it 0.20 m is
$W = Fd = 2.5 \text{ nt} \times 0.20 \text{ m} = 0.50$ joules

(2) Under ideal conditions, the potential energy is equal to the work done in causing the distortion. Hence, P.E. = 0.50 j.

When the spring is released, its kinetic energy as the loop at its end passes the original rest position is also 0.50 joules, since all the P.E. originally stored in it has been converted to K.E. at this point.

The explosive charge propelling a bullet has chemical potential energy which, for simplicity, may be viewed as energy stored in the "distortion" of the molecular structure of the powder.

Suppose a 4.0-gm bullet is given a muzzle velocity of 700 m/sec by its charge. Can we find the potential energy of the powder using only this data? Yes, we can.

Find the kinetic energy of the bullet as it leaves the gun, then convert this to the potential energy of the charge propelling the pellet.

What's the answer?

(21)

A 1,960 joules.

B 1,400 joules.

C 980 joules.

D None of these answers is right.

YOUR ANSWER --- B

Do you recall that we emphasized the level of position (1) of Figure 9 on page 60 as the zero reference level? Then, when the bob passes through (1), its height is zero. Therefore, with reference to this arbitrarily chosen zero height, the potential energy of the bob must also be zero since

$$P.E. = mgh$$
$$P.E. = m \times g \times 0 = 0$$

On this basis, your answer cannot be correct.

Please return to page 62 and choose the correct answer.

YOUR ANSWER --- B

You are correct. The weight of the safe does not enter into the solution of this problem.

The <u>horizontal</u> force is 450 nt and the <u>horizontal</u> displacement is 25 m; hence from W = Fd we have:

W = 450 nt x 25 m = 11,250 joules, or to two significant figures, <u>W = 11,000 joules</u>.

Our definition of work as the force in the direction of motion times the distance moved was developed to agree with the idea that equal amounts of fuel will supply equal amounts of energy. Will this definition provide us with information about the <u>energy</u> possessed by a moving body? If it cannot do so, it has little value as a definition.

To continue, please turn to page 117.

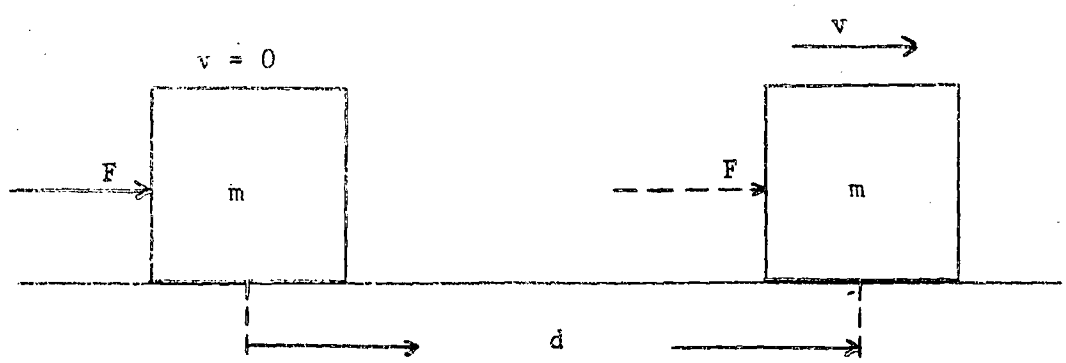


Figure 6

In Figure 6, a constant force F is applied to a mass m on a frictionless table. The mass accelerates as a result of the force, takes on new velocity, and travels the distance d while the force is acting.

Work was done by the force F on the mass m according to our definition. This work is the measure of the energy transferred to the mass m according to our definition. Now we should like to find an expression for the energy in terms of the motion of the body.

As the diagram shows, the mass starts with an initial velocity equal to __________ and accelerates to a velocity v. Write the missing word, then turn to page 91.

YOUR ANSWER --- C

Any or all of the listed characteristics could be found from this data. However, we asked for the one that could be found most conveniently. By this we mean, which relationship--the equation for finding work, K.E. or P.E.--can use these data as direct substitutions?

You answered potential energy. But to find P.E., you must know the weight of the stone and the height to which it was raised. Neither of these quantities is given in the data, hence it is not convenient to find P.E. first.

Please return to page 171; then pick a better response.

YOUR ANSWER --- A

You are correct.

$$W = k''Fd$$
$$W = (1) \times nt \times m$$
$$W = nt\text{-}m.$$

You will remember that we sometimes give another name to a derived unit to reduce its awkwardness. We did this with the unit of force, the kg-m/sec^2 by calling it one newton.

The same thing is done with the unit for work, the newton-meter. It is called a joule after James Prescott Joule, the English scientist who contributed much of mechanics to physics. (For the pronunciation of the joule: There are probably as many authorities who pronounce it "jewel," as there are who say "jowl.") So remember: 1 joule = 1 newton-meter.

Before continuing, please turn to page 181 in the blue appendix.

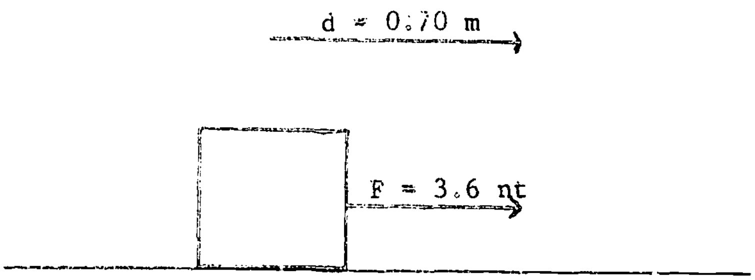


Figure 2

Suppose, as in Figure 2, a force of 3.6 newtons is applied horizontally to move the block a distance of 0.70 meters. Energy is required to overcome the friction between the block and the table upon which it rests. Which answer below does NOT properly express the work done?

(5)

A 2.5 nt-m.

B 2.5 joules.

C 2.52 nt/m.

YOUR ANSWER --- A

You are correct. At ground level, or reference zero level, the height of the ball is zero so that its potential energy is zero, too. All of the P.E., however, is tranformed into K.E. at the time of impact.

Getting back to our problem, we have seen that at t = 0, the P.E. = 432 j and the K.E. = 0; that at t = 3.00 sec, the P.E. = zero and the K.E = 432 j. Our next task is to find the distribution of energy for t = 1.00 sec.

We'll do this in several steps, and at the same time, stress a very important idea. Let's start by finding the P.E. of the ball at t = 1.00 sec.

The ball starts to fall from a height of 44.1 m. First let's determine how far it fell during that first second and then, by subtracting this figure from the original height of 44.1 m, we can find its height above ground at the end of 1.00 sec. From this, the P.E. follows easily. Thus:

$$d = \tfrac{1}{2}at^2$$

(This is the equation for distance in free fall where a = g = 9.80 m/sec^2, and t = 1.00 sec.)

so d = ?

Work this out to three significant figures, write your answer, then turn to page 58 to verify the result.

YOUR ANSWER --- C

Correct! The watt is the same as a joule per second. A joule is a unit of work (or energy); hence the joule per second is a measure of the time rate of doing work or expending energy which, of course, is the same as power.

NOTEBOOK ENTRY
Lesson 12

(Item 5)

(e) One joule = 0.738 ft-lb. Thus, the joule is smaller than the foot-pound. Roughly, 1 joule is 3/4 of a ft-lb.
(f) One horsepower (HP) is defined as 550 ft-lb/sec.
(g) 1 HP = 550 ft-lb/sec = 746 j/sec = 746 watts.

We promised that there would be no problems using English units, but we should solve a few samples in the MKS system. We'll run through a simple one first.

An electric motor which runs a drill press consumes 500 watts of electrical power. Assuming that all the electricity used is converted into useful mechanical work, how much work does a drill press do each minute that it turns?

(36)

A 500 watt-sec.

B 500 joules.

C Neither of these.

YOUR ANSWER --- C

You are absolutely correct. Both answers are wrong. Here is the right solution:

$$m = 2.0 \text{ gm} = 2.0 \times 10^{-3} \text{ kg}$$

$$K.E. = \tfrac{1}{2}mv^2$$

$$v = 6.0 \text{ cm/sec} = 6.0 \times 10^{-2} \text{ m/sec}$$

$$K.E. = \frac{2.0 \times 10^{-3} \text{ kg} \times (6.0 \times 10^{-2} \text{ m/sec})^2}{2}$$

$$K.E. = 36 \times 10^{-7} \text{ j} = \underline{3.6 \times 10^{-6} \text{ j}}$$

We have seen that work ($W = Fd$) is used as a measure of the amount of kinetic energy given to a body. Throughout our discussion thus far, we have implied that all of the work done on a body is used for the sole purpose of giving kinetic energy to it. In other words, we assume <u>ideal conditions</u> in which there are no friction forces of any kind to force us to do work to overcome them. Later we shall study the effect of friction, but for the present, let us continue our analysis on the basis of ideal conditions.

Please turn to page 123.

Let's emphasize again that under ideal conditions the kinetic energy acquired by a mass is exactly equal to the work done upon that mass in transferring energy to it. As an illustration of this, how would you answer the following question:

A boy pushes horizontally on a 72-kg frictionless cart with a constant force of 64 nt until it attains a speed of 4.0 m/sec. Over what distance did this constant force have to act on the cart?

(15)

A 2.25 m.

B 9.0 m.

C 18.0 m.

D None of these is correct.

YOUR ANSWER --- C

Certainly it can! In Figure 6 on page 117, the constant force F causes the mass m to accelerate at a rate a; hence the Second Law is applicable, and we may say that $F = ma$. Thus, in: $W = Fd$, we may replace the F with ma and obtain: $W = mad$.

Now let us proceed further. In the lesson on uniformly accelerated motion, we derived an expression which relates the final velocity of a body starting from rest to its acceleration and the distance it travels. To refresh your memory you may go back to the notes on Lesson 6 (Item 3).

Choose from the list below the equation which gives the relationship between final velocity, acceleration and distance.

(11)

A $v^2 = 2ad$

B $d = \frac{1}{2}at^2$

C $v = at$

CORRECT SOLUTION:

$P = 5.0 \times 10^3$ j/sec
$m = 3.2 \times 10^3$ kg
$v = 2.0$ m/sec

These facts are given. But note that the mass of the block does not enter into the calculations. First, we find the unbalanced force applied to the block thus:

$$P = Fv$$
$$F = P/v = \frac{5.0 \times 10^3 \text{ j/sec}}{2.0 \text{ m/sec}}$$
$$F = 2.5 \times 10^3 \text{ nt}$$

Now, since the block moves with uniform speed horizontally, the unbalanced applied force F must exactly overcome the force of friction; hence the two are equal and

$$F_{fric} = \underline{2.5 \times 10^3 \text{ nt}}$$

Obviously, the applied force and the retarding force act in opposite direction. Since they are equal, the block is in dynamic equilibrium horizontally; hence it maintains a constant speed.

Now that we have mentioned directions--really for the first time in this lesson--we might expect you to ask about the vector or scalar nature of work, energy, and power. Have you wondered whether these are vector or scalar quantities? You should have, you know.

Curiously enough, work and energy are <u>scalar</u> quantities. The proof of this statement must await your study of higher mathematics, so you must accept this statement on faith for the present. Power is a quotient; it is the rate of doing work, expending energy, or work per unit time. Now, if work is a scalar and time is also a scalar quantity, what must power be?

(40)

A A vector quantity.

B A scalar quantity.

YOUR ANSWER --- A

This answer is incorrect.

The determination of the bullet's K.E. as it leaves the muzzle of the rifle involves:

$$K.E. = \frac{1}{2}mv^2$$

To get the above answer, did you forget to follow one of the directions implied in this equation? Check the equation again.

Please return to page 114 and select a better answer.

Now let's turn our attention to the total momentum of the system. Designating rightward motion as (+) and leftward motion as (-), then

$$\text{total } p = mv + (-mv)$$

Thus, for balls of 0.20 kg each with velocities of +10 m/sec and -10 m/sec respectively, what is the total momentum of the system?

(41)

A The total momentum of the system is 4.0 kg-m/sec.

B The total momentum of the system is 20 joules.

C The total momentum of the system is zero.

YOUR ANSWER --- C

You don't have to "determine" the acceleration of the block as a freely falling body under ideal conditions. You should <u>know</u> its value.

In solving this problem, we shall want to know the acceleration of the block as it falls. What value will you use? (Refer to Figure 7 on page 120).

(19)

A 9.8 m/sec

B 9.8 m/sec^2

C 980 cm/sec^2

D 32 ft/sec^2

YOUR ANSWER --- C

Almost, but not quite. Perhaps you noted that the units given were pounds and feet, but were not clear on how to combine these units. Since there is no single word in the English system to take the place of "joule" in the MKS system, we form the English unit of work in the same way we combined units for our original metric term. You should be able to select the right answer now.

Please return to page 87 and choose again.

YOUR ANSWER --- D

This is incorrect; one of the answers given is correct.

The determination of the bullet's K.E. as it leaves the muzzle of the rifle involves:

$$K.E. = \frac{1}{2}mv^2$$

In deciding on the above answer, did you forget to follow one of the directions implied in this equation?

Check the equation again.

Please return to page 114 and select a better answer.

YOUR ANSWER --- A

Actually, any or all of these quantities could be found from this data. However, we asked for the one that could be found most conveniently. By this we mean, which relationship--the equation for finding work, P.E. or K.E.--can use these data as direct substitutions?

You answered work done. But to determine the work done you must know the force applied and the distance through which this force moved the stone in raising it from the ground to its final height.

You don't know either of these facts directly; hence it would not be most convenient as a first step to find the work done.

Please return to page 171. Choose an answer that meets the qualifications of the data.

YOUR ANSWER --- C

You are correct. When the substitution and simplification are handled properly, you obtain W = mad and since $a = v^2/2d$ then $W = m \times (v^2/2d) \times d$ so

$$W = \frac{mv^2}{2}$$

This last relationship states that the original work done by the constant force F moving the mass over the distance d has been used to give the body an amount of energy equal to $\frac{1}{2}mv^2$. We have succeeded, therefore, in expressing the energy of the body in terms of its mass and velocity, without any reference whatever to original force that did the work, or to the distance that the body moved while the force acted. Thus, this statement of the quantity of energy in the moving mass does not depend on its history. Any mass m moving with a speed v has an amount of energy equal to $\frac{1}{2}mv^2$ regardless of the method used to transfer the energy to it.

The energy of a mass in motion is called kinetic energy to distinguish it from another type of energy to be discussed in the next lesson. We will symbolize kinetic energy as K.E. In view of the method used to derive the equation K.E. = $\frac{1}{2}mv^2$, which of the following would be a suitable energy unit in the MKS system?

(13)

A The joule.

B The foot-pound.

C The newton.

YOUR ANSWER --- A

Not always.

In any conversion from P.E. to K.E., after most of the potential energy has been expended in increasing the velocity of a mass, the K.E. is much greater than the residual P.E.

Similarly, in a conversion involving a change from K.E. to P.E., the K.E. is much greater than the P.E. when the process first begins.

Please return to page 167. Choose a better answer.

YOUR ANSWER --- A

Not quite. Let's remember to keep the units right. You know that acceleration cannot be measured in meters per second.

Please return to page 128 and select the right answer.

CORRECT SOLUTION: We hope you used the easy way!

At a height of 12 meters: P.E. = 2h = 8.0 nt x 12 m = 96 joules. The total energy of the system is, then, 96 joules. Half-way down, the height is halved; hence the P.E. is also halved. Thus, the new P.E. is 48 joules. But since the total energy = K.E. + P.E. then the K.E. at the half-way mark is also 48 joules.

NOTEBOOK ENTRY

Lesson 12

(Item 4)

(d) In the case of a body in free fall, potential energy changes linearly to kinetic energy, since potential energy is directly proportional to height above the reference zero. To find the K.E. of a body in free fall at any height, determine its P.E. at the initial height and its P.E. at the required height. The difference between these is the K.E. of the falling body at that height, provided that the falling body started from rest.

Before concluding this lesson, there is another kind of physical quantity we must discuss. To illustrate this quantity, we should like to tell you a short anecdote.

Turn to page 136, please.

A horse dealer advertised two work horses for sale. One, a shiny brown stallion, was to sell for $800; the other, a beautiful black mare, was to go for $600. A farmer who looked at the horses saw that they were both in good shape and appeared equally strong. He pointed to a wagon full of hay and asked the dealer if the brown stallion could pull the wagon to the top of a nearby hill. The deal said, "Yes." The farmer then asked if the black mare could pull the same wagon up the same hill and again the dealer said, "Yes."

"But," said the farmer, "if both horses can do the same job, why does one cost $200 more than the other?" What do you think the dealer told him? Think it over! Then turn to page 24.

CORRECT ANSWER: The kinetic energy of the meteor is 2.0×10^{13} joules.

We hope you remembered to square the speed. That is:

$$K.E. = \frac{mv^2}{2} = \frac{4.4 \times 10^3 \text{ kg} \times (3.0 \times 10^6 \text{ m/sec})^2}{2}$$

$$= 2.2 \times 10^6 \text{ kg} \times 9.0 \times 10^6 \text{ m}^2/\text{sec}^2 = 19.8 \times 10^{12} \text{ joules}$$

$$= 20. \times 10^{12} \text{ joules to two significant figures, or } \underline{2.0 \times 10^{13} \text{ joules}}.$$

Note that joules is u[illegible] abbreviated j. The meteor has a pretty large kinetic energy, doesn't [illegible] You'd expect it, of course, because it has a large mass and a large velocity.

Now let's compute the kinetic energy of a 2.0 gm block moving along a frictionless table at a speed of 6.0 cm/sec. (Watch those units!) What is the kinetic energy of this block?

(14)

A 3.6×10^{-8} j

B 6.0×10^{-5} j

C Neither of these.

YOUR ANSWER --- B

You are correct. There is more than enough experimental evidence available to permit us to conclude that this always happens.

A system starts with a certain amount of energy that has been put into it by work done on the system. Regardless of the kinds of conversions of energy that occur, P.E. to K.E. and vice versa, the total energy is always the sum of the individual energies at any given time. Or, under ideal conditions, the total energy of the system remains constant, that is, energy is conserved.

NOTEBOOK ENTRY
Lesson 12

4. Conservation of Energy for Ideal Conditions

(a) Ideal conditions are conditions for which friction, air, resistance, and allied effects are considered to be zero.

(b) Under ideal conditions, the energy of an isolated system is conserved. Work may be transformed to either potential or kinetic energy, or one kind of energy may be converted to the other, without loss or gain.

(c) In an ideal interaction, the total energy of the system is the sum of the potential and kinetic energies, regardless of the conversions that may take place from one kind to the other.

Before continuing, please turn to page 185 in the blue appendix.

Notebook Check

Referring to the notes for this lesson, what does notebook entry 1(c) tell us?

(28)

A It presents the equation for work.

B It presents an illustrative example.

C It gives the units of work.

D It defines kinetic energy.

CORRECT ANSWER: You might have written either of these two forms:

$$(1)\quad v = \sqrt{2ad} \quad \text{or} \quad (2)\quad v^2 = 2ad$$

We want to find the K.E. of the block as it reaches the ground after having fallen freely from rest for 3.00 meters. Since K.E. = $\frac{1}{2}mv^2$, it is sensible to use equation (2), because it is the square of the velocity that we shall ultimately substitute in the K.E. equation.

Are you with us? We'll find the value for v^2, as we have said, by applying equation (2) above using 9.8 m/sec^2 for "a" and 3.00 m for "d" So,

$$v^2 = 2 \times 9.8\ \text{m/sec}^2 \times 3.00\ \text{m}$$

$$v^2 = 58.8\ \text{m}^2/\text{sec}^2$$

All right. We know that the mass m is 5.00 kg and that v^2 is 58.8 m^2/sec^2. Calculate the K.E. of the block as it strikes the ground. When you have the answer, please select the only pertinent true statement below.

(20)

A We were justified in saying that 147 joules of energy were stored in the block as the result of the 147 joules of work done in raising it.

B We were not justified in saying that the work done in raising the block to the shelf was stored as potential energy in the block.

C The answer obtained for the K.E. of the block does not justify any conclusion at all.

YOUR ANSWER --- C

You're right.

From the definition of power we have:

$$P = \frac{W}{t}$$

Since work is to be determined we must solve the equation for W:

$$W = Pt$$

The power consumed is 500 watts and the time under consideration is 1 minute. Now, a watt is a joule per second (or a j/sec) and 1 minute is 60 seconds, so

$$W = 500 \text{ j/sec} \times 60 \text{ sec}$$
$$\underline{W = 30{,}000 \text{ j}}$$

Very often, especially in flash photography, you will run across a unit called the watt-second. (w-sec). Look at the solution above carefully while you try to choose the only true statement from the group below:

What is the watt-second?

(37)

A A unit of force and is the same as a newton.

B A unit of energy and is the same as a joule.

C A unit of power and is the same as a joule.

D A unit of work and is the same as a newton.

You have now completed the study portion of Lesson 12 and your Study Guide Computer Card and A V Computer Card should be properly punched in accordance with your performance in this Lesson.

You should now proceed to complete your homework reading and problem assignment. The problem solutions [illegible]t be clearly written out on 8½" x 11" ruled, white paper, and then subm[illegible] with your name, date, and identification number. Your instructor will [illegible]de your problem work in terms of an objective preselected scale on a Problem Evaluation Computer Card and add this result to your computer profile.

You are eligible for the Post Test for this Lesson only after your homework problem solutions have been submitted. You may then request the Post Test which is to be answered on a Post Test Computer Card.

Upon completion of the Post Test, you may prepare for the next Lesson by requesting the appropriate

1. study guide
2. program control matrix
3. set of computer cards for the lesson
4. audio tape

If films or other visual aids are needed for this lesson, you will be so informed when you reach the point where they are required. Requisition these aids as you reach them.

Good Luck!

YOUR ANSWER --- D

You are correct. In climbing the ladder, the boy uses muscular force to press downward on each rung, and the rungs push upward on him with the same force. So, to raise his weight of 120 lb, he must push with a force of 120 lb, the reaction force being in the direction of the motion.

So that you can convert these figures to metric MKS units, make this notebook entry:

NOTEBOOK ENTRY
Lesson 12

(Item 1)

(e) Conversion Ratios

1 pound = 4.45 newtons
1 joule = 0.738 ft-lb

Apply the principles you have learned thus far to the solution of this problem: A 400-lb (1,800 nt) safe is moved along a level floor by an applied horizontal force of 450 nt. If the safe is moved 25 meters, how much work is done?

(9)

A 10,000 joules.

B 11,000 joules.

C 45,000 joules.

YOUR ANSWER --- B

You are correct.

In the anecdote about the horse-dealer and farmer, it should have been quite obvious that the horse that could get the job done faster would be more valuable. The idea of speed, of course, involves the time required to do a specified amount of work.

The same is true of the book-stacking example: You would be a more desirable employee than your little brother because you could stack the books 10 times as fast as he could. Here again, the time you would need to complete a particular job would be considerably smaller.

From a practical point of view, then, we need a physical means by which to grade a horse, a machine, or a person as to ability to get a job done quickly. So we proceed to invent such a means by defining a new quantity called power.

NOTEBOOK ENTRY
Lesson 12

5. Power

(a) Power is defined as the time rate of doing work.

(b) This definition in the form of an equation is:

$$P = \frac{W}{t} \quad \text{or} \quad P = \frac{Fd}{t}$$

(c) As shown, power is inversely proportional to the time required to do a specific amount of work. That is, an animal or machine that needs more time to do the work has less power, comparatively.

(d) In the MKS system, the unit of power is the j/sec or joule per second.

A 500-nt boy can climb a 6.0-meter ladder in 15 seconds. What power does he use?

(34)

A 45,000 j/sec

B 200 j/sec

C Neither answer is correct.

CORRECT ANSWER: The potential energy of the ball at a height of 39.2 meters is: P.E. = wh = 9.8 nt x 39.2 m = <u>384 joules.</u>

<u>Write this figure down and put it aside for later use.</u>

The next step is to calculate the kinetic energy of the ball after it has fallen for 1.00 sec. Since K.E. = $\frac{1}{2}mv^2$, we must compute the ________ of the ball at this time. What's the missing word?

(25)

A Mass.

B Speed.

YOUR ANSWER --- B

Good work! You're absolutely correct. A watt is a joule per second If we now replace the watt with the joule per second, we have this:

1 watt-second = 1 joule/sec x sec = 1 joule

The joule and watt-second can be used interchangeably in any problem In straightforward mechanics situations, the joule is usually preferred; but when electricity is involved, the watt-second is often employed.

You probably know that your electric bills are based on the readings of the power company's <u>kilowatt-hour</u> meters. These may be located in your basement, in an apartment enclosure, or in a waterproof housing outside your house. Make it a point to inspect one of these meters and assure yourself that it measures kilowatt-hours. Ask your folks to show you one of their bills and observe that the charge is based on some figure such as 5 cents per kilowatt-hour.

What is the kilowatt-hour?

It is a unit of ____________.

(38)

A Energy.

B Power.

C Power per unit time.

YOUR ANSWER --- B

You are correct. Power is a quotient of two scalars; hence it, too, is a scalar.

Thus, work, energy, and power are all scalar quantities. When a man or machine does work or expends energy, it makes no difference as to the direction of the force in W = Fd, for the work done is merely a number and a unit without directional significance. If a machine produces 15,000 joules of energy, this is the energy output regardless of the direction in which motion may occur.

Contrast this with <u>momentum</u>. Momentum is a vector quantity and its direction must always be specified if we are to know how it acts.

For example, a billiard ball rolls along a table from the north side toward the south side with a uniform velocity of 10 m/sec. If the mass of the ball is 0.20 kg, then the momentum of the ball is

$$\vec{p} = m\vec{v} = 0.20 \text{ kg} \times 10 \text{ m/sec} = 2.0 \text{ kg-m/sec } \underline{\text{toward the south}}$$

and its kinetic energy is

$$K.E. = \tfrac{1}{2}mv^2 = \frac{0.20 \text{ kg} \times 100 \text{ m}^2/\text{sec}^2}{2} = \underline{10 \text{ joules}}$$

As you venture into more advanced physics, the vector nature of momentum and the scalar nature of energy will assume increasing importance in your thinking.

Please turn to page 83 to continue.

YOUR ANSWER --- A

You forgot something!

The equation for kinetic energy is K.E. = $\frac{1}{2}mv^2$ not $\frac{1}{2}mv$.

Does this give you the clue to your mistake? We hope so.

Please return to page 123. Choose the right answer this time.

YOUR ANSWER --- C

You are right. The equation we want is: K.E. = $\frac{1}{2}mv^2$.

We know the mass of the bomb is 1,020 kg. We are also told that the bomb falls 2/3 of the way down from its original height, a distance of 6.00 x 10^3 m. The velocity at this height could then be found from:

$$v^2 = 2ad = 2gh$$

So, the kinetic energy is:

$$K.E. = \frac{1.02 \times 10^3 \text{ kg} \times (2 \times 9.80 \text{ m/sec}^2 \times 6.00 \times 10^3 \text{ m})}{2}$$

$$K.E. = 1.02 \times 9.80 \times 6.00 \times 10^6 = \underline{6.00 \times 10^7 \text{ joules}}$$

After the bomb has fallen 2/3 of the way, its kinetic energy is 6.00 x 10^7 joules.

Now, how about the simple way to do the same problem?

Please turn to page 149.

Suppose we calculate the P.E. of the bomb at the altitude of the plane:

$$P.E. = mgh = 1.02 \times 10^3 \text{ kg} \times 9.80 \text{ m/sec}^2 \times 9.00 \times 10^3 \text{ m}$$

$$= 9.00 \times 10^7 \text{ joules.}$$

After the bomb has fallen 2/3 of the way down, its height has decreased by 2/3. Hence its P.E. has decreased by 2/3 of its former value, and thus 2/3 of the total has been converted to kinetic energy. Thus,

$$K.E. = 2/3 \times 9.00 \times 10^7 \text{ joules} = \underline{6.00 \times 10^7 \text{ joules}}$$

You see, we get the same answer without becoming involved with $v^2 = 2gh$.

What is the kinetic energy of an 8.0-nt ball that has fallen half-way down from a height of 12 meters? Write your solution; then turn to page 135.

YOUR ANSWER --- C

You are correct.

Since work is calculated using W = Fd, then the weight of the block must be determined from its mass. Newton's Second Law states that:

$$w = mg$$

so that:

$$w = 5.00 \text{ kg} \times 9.8 \text{ m/sec}^2$$
$$w = 49 \text{ nt}$$

Then:

$$W = 49 \text{ nt} \times 3.00 \text{ m}$$
$$= \underline{147 \text{ joules}}$$

So far, so good. Now, in moving the block over path BC in Figure ? on page 170 which is horizontal, there are no retarding forces acting on it at all; gravity has no horizontal component and we assume friction is zero. If there are no retarding forces, then no force is required to keep the block moving horizontally toward the right. It is first accelerated and then decelerated to its final position, where it is at rest. Therefore, no work is done in moving the block along path BC.

The total amount of work done, then, in placing the block on the shelf is 147 joules. Let's bear this in mind. Now the block rests motionless on the shelf. How much kinetic energy does it have?

(17)

A It has no kinetic energy.

B It has 147 joules of kinetic energy.

C The data given is not sufficient to calculate the kinetic energy.

YOUR ANSWER --- C

The vector nature of momentum compels us to conclude that when two balls of equal mass and speed, each moving in opposite directions, are considered as a system, then the total momentum of this system is zero. This is quite reasonable. Suppose the balls were made of putty; suppose further that if they were allowed to collide head-on, they would stick together in an inelastic collision. Then you could predict, almost intuitively, that they would come to a dead stop after impact, the final speed being zero. In that case the total momentum would also be zero. Note that this result can be obtained only if the masses are equal and the speeds have the same magnitudes in opposite directions.

But what of the balls' energies in the same collision situation? Here again, since the balls come to rest, final speed is zero. Then the kinetic energy, too, must be zero. This creates an apparent inconsistency: If the net K.E. of the system is the sum of the individual K.E.'s before collision and it is zero after collision, what happened to the Principle of Conservation of Energy? No such inconsistency is associated with the interchange of momenta, because the vector nature of momentum tells us that the total momentum is zero before and after the collision. But this does not apply to kinetic energy.

We leave you with this dilemma in closing this lesson. Think about it. The problem will be resolved in the next lesson.

Please go on to page 152.

In summary, work is defined as the product of the component of a force along the direction of motion and the distance moved as a result of the action of this component. In other words, work is directly proportional to the component of force causing motion and to the magnitude of motion thus produced. In mathematical shorthand this reads:

$$W = Fd$$

Remember that F is the component in the direction of motion and that d is the displacement caused by the component.

In the MKS system, work is measured in newton-meters, since F is stated in newtons and d is stated in meters. For brevity and convenience, a newton meter is called a joule, abbreviated j.

Please turn to page 141.

YOUR ANSWER --- A

You are correct. Since the definition of kinetic energy was obtained directly from the definition of work, then energy and work units must be identical. In addition, if you substitute units in the K.E. equation, the result is joules. That is:

$$KE = \frac{1}{2}mv^2 = kg \times \frac{m^2}{sec^2} \quad \text{or breaking this up into two parts,}$$

$$K.E. = \underbrace{\frac{kg\text{-}m}{sec^2}}_{nt} \times m = \text{newton-meters} = \text{joules.}$$

NOTEBOOK ENTRY
Lesson 12

2. Kinetic Energy

(a) Kinetic energy is energy transferred to a mass in the form of an increase of velocity.

(b) The kinetic energy of a body starting from rest is equal to the work done in causing the body to attain its state of motion.

(c) $K.E. = \frac{1}{2}mv^2$. Regardless of the method used to cause mass m to take on a given velocity v, its kinetic energy is always measurable as one-half the product of its mass and the square of its velocity.

(d) Kinetic energy is measured by the work done to cause a mass to achieve a given velocity starting from rest; hence the energy unit is the same as the work unit, namely the joule.

Imagine yourself in a space ship looking out through the observation port. Suddenly, in the distance, a meteor appears; you grab your super-instruments and measure its mass and speed as it goes by. Its mass is 4.4×10^6 kg; its speed is 3.0×10^3 m/sec. A quick calculation shows its kinetic energy to be _________ joules. What answer do you get? Write it; then please turn to page 137.

This page has been inserted to maintain continuity of text. It is not intended to convey lesson information.

This page has been inserted to maintain continuity of text. It is not intended to convey lesson information.

YOUR ANSWER --- A

Quite right. If the block is at rest, then $v = 0$ and $K.E. = \frac{1}{2}mv^2 = 0$.

But think a moment. It required 147 joules of work to get the block to the shelf. And we know that work is a measure of energy. So, if 147 joules of work were done on the block, it has to have 147 joules of energy, somehow. Otherwise much of the reasoning that led us to this point in our study has been meaningless.

The answer, surprisingly, is quite simple. The block does have 147 joules of energy, but it is not kinetic energy. This type of energy is called potential energy, abbreviated P.E.

Here's how we arrive at this conclusion. We have done 147 joules of work to raise the block to the shelf. If the shelf were now removed, the block would return to the ground as a freely falling body gathering kinetic energy as it accelerated. Thus, in its raised position on the shelf, we have apparently stored in the block a capability to produce kinetic energy if the block is allowed to return to the position where work began. This stored capability is called potential energy (P.E.) because it can turn into kinetic energy.

Please go on to page 157.

The argument is convincing, but needs just a bit of quantitative bolstering to really tie up the loose ends.

We propose to show now that there are 147 joules actually stored in the gravitational field between the block on the shelf in Figure 7 on page 170 and the earth. The method is mathematical, but quite easy to follow. We'll calculate the K.E. that the block will develop as a freely falling body when allowed to drop to the ground from the height at which it now rests, 3.00 meters.

The mass of the block is 5.00 kg. What quantity should we determine now in order to calculate the kinetic energy acquired by the block at the instant it reaches the ground?

(18)

A Its velocity when it reaches the ground.

B Its initial velocity.

C Its acceleration as a freely falling body.

YOUR ANSWER --- B

Your choice indicates that you didn't watch closely enough; the "v" in the given equation was not squared. Perhaps you just don't remember the equation; in that case, you had better use your notes to refresh your memory.

Please return to page 32. You should be able to pick the right answer.

YOUR ANSWER --- A

This is not correct.

Work *is* done on the block, because a force must be exerted upward on it to raise it from the ground. If the force is a constant one, then it must continue to act over the entire distance of 3.00 meters. So, we have a force in the direction of motion and a distance moved; this automatically means that work has been done on the block.

Please return to page 170 and try again.

YOUR ANSWER --- D

This is not true.

One of the answers does contain just such a quantity. Vertical distance is height, and a ladder is a means of attaining height. What new concept or idea has been introduced?

Please return to page 24. You can find the right answer.

YOUR ANSWER --- A

You misinterpreted the definition of power.

Power is the time rate of doing work and is calculated from:

$$P = \frac{W}{t}$$

Note that the t is in the denominator. Apparently you thought it was in the numerator and multiplied the work by the time. This is, of course, incorrect.

Please return to page 143 and select another answer.

YOUR ANSWER --- A

This is incorrect.

The way to determine the meaning of a derived unit like the watt-second is to replace the watt with its synonymous unit, the joule per second, and <u>then</u> simplify the combination, if possible.

Try it. Then please return to page 140 and choose the right answer.

YOUR ANSWER --- A

This is not correct.

The substitution brings about this first result:

$$W = m \times \underset{\substack{\uparrow \\ a}}{\frac{v^2}{2d}} \times d$$

But when this is simplified, you don't get the answer you selected.

Please return to page 82 and choose a better answer.

YOUR ANSWER --- C

You are correct. Speed is defined $\Delta d/\Delta t$, or change of displacement with respect to time. (Note: $\Delta d/\Delta t$ is a definition of velocity, if the situation calls for vectors rather than scalars. Since we have not yet discussed the nature of work, energy and power in this respect, we shall continue to use scalar quantities like speed.)

Thus, if $\Delta d/\Delta t$ means speed, then the power equation can very well be written:

$$P = Fv$$

in which v = speed and replaces $\Delta d/\Delta t$.

Let's return to the problem: The motor is rated at 10.0 kw and is to raise a load of 2.75×10^4 kg. How fast will the load go up? (The speed is to be given in meters per minute.)

Can you work this without further help? Try it. Take your time and be careful with units. Write out your whole solution; then follow our solution as presented when you turn to page 89.

YOUR ANSWER --- A

No, it is not.

Work is a scalar quantity; time is a scalar quantity. Power = work/time or scalar/scalar. Although we have never explicitly said so, it should be obvious that one cannot hope for a vector quantity to emerge from a division of one scalar by another. Where would the direction-factor have its source?

We know this: A vector multiplied or divided by a scalar yields a vector quantity. For example: $v = \Delta d/\Delta t$; also $F = ma$. To this we can add: A scalar multiplied or divided by another scalar yields a scalar quantity.

Please return to page 125 and choose the alternative answer.

YOUR ANSWER --- B

We consider this answer a mechanical blunder. We are certain you know that the foot-pound would never be a unit for any physical quantity in the MKS system.

So, return to page 132, please, and choose the right answer.

YOUR ANSWER --- B

Good! The kinetic energy is obtained from:

$$K.E. = \frac{mv^2}{2} = \frac{1.00 \text{ kg} \times (9.8 \text{ m/sec})^2}{2} = \underline{48.0 \text{ joules}}.$$

Now let's see where we stand. We found that after 1.00 sec of free fall, the potential energy of the ball had decreased from its initial value of 432 joules to a new value of 384 joules. (Remember? You wrote the new value for later use.)

Next, we calculated the kinetic energy of the ball after 1.00 sec of free fall, 48.0 joules.

So the ball has at this time

384 joules of P.E. and
48.0 joules of K.E.

The total energy of the ball is thus distributed between its potential and kinetic energies. But, what is most important, its total energy is still 432 joules because 384 + 48.0 = 432. Whenever this experiment is performed under nearly ideal conditions, the same important fact results.

During a conversion from P.E. to K.E., or vice versa, how is the energy always distributed?

(27)

A The P.E. is normally greater than the K.E.

B The total energy is the sum of the instantaneous values of the P.E. and K.E.

C The residual P.E. after time t is the sum of the total energy and the K.E. at that instant.

YOUR ANSWER --- C

Vertical distance has played an important role throughout our development of the concepts of work and energy. The very definition of potential energy involves a "height" factor. So "height" or vertical distance is not new to us in the concepts of work and energy.

Please return to page 24 and pick a better answer.

YOUR ANSWER --- B

Very good! To solve this, you must remember that the conditions are ideal, and that all of the work done by the boy goes into developing the kinetic energy of the cart. So, the work done is:

$$(W = Fd) \qquad W = 64 \text{ nt} \times d \text{ meters}$$

The energy the cart has when the force stops acting is

$$(K.E. = \tfrac{1}{2}mv^2) \qquad K.E. = \frac{72 \text{ kg} \times (4.0 \text{ m/sec})^2}{2}$$

Since all of the work turns into kinetic energy, then W and K.E. may be equated and we have:

$$64 \text{ nt} \times d \text{ meters} = \frac{72 \text{ kg} \times (4.0 \text{ m/sec})^2}{2}$$

$$d = \frac{72 \text{ kg} \times 16 \text{ m}^2/\text{sec}^2}{2 \times 64 \text{ nt}}$$

$$d = 9.0 \text{ m.}$$

Please turn to page 183 in the blue appendix.

Now let's consider another facet of the energy concept.

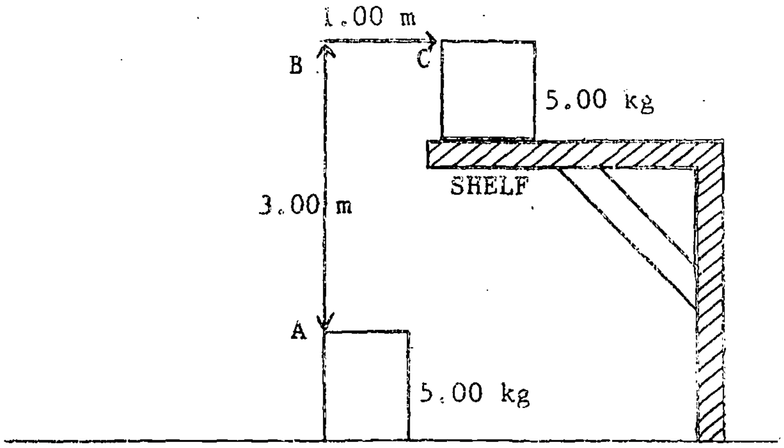


Figure 7

As shown in Figure 7, a 5.00-kg block is raised from the floor to a shelf 3.00 m high by moving it vertically a distance of 3.00 m and then horizontally a distance of 1.00 m to the shelf. How much work is done on the block over path AB, from the floor vertically upward to shelf level?

(16)

A No work is done.

B 15.0 joules.

C 147 joules.

D None of the above answers is correct.

YOUR ANSWER --- C

You are correct. The kinetic energy is:

$$K.E. = \frac{mv^2}{2} = \frac{4.0 \times 10^{-3}\ \text{kg} \times (7.0 \times 10^2\ \text{m/sec})^2}{2}$$

$$= \frac{4.0 \times 10^{-3}\ \text{kg} \times 49 \times 10^4\ \text{m}^2/\text{sec}^2}{2}$$

$$= \underline{980\ \text{joules}}$$

Here's another problem you can solve. (COPY IT.)

A 20-kg stone is dropped from a certain height and strikes the ground with a speed of 12 m/sec. From what height was it dropped?

Think about this problem for a few minutes. You are told the mass of the stone and its velocity when it reaches ground level. Which of the following is most conveniently determined from this data?

(22)

A The work done in raising the stone to the height from which it finally falls.

B The kinetic energy of the stone when it reaches ground level.

C The potential energy of the stone.

YOUR ANSWER --- C

Think what this would imply if it were true!

It means that the residual P.E. would be greater than the total energy of the system by an amount equal to the K.E. at the time. This is impossible, of course. It's like saying that a wedge cut out of a perfectly uniform apple pie is heavier than the whole pie! Or that a dime weighs more than a pocketful of dimes!

There is a better answer available. Please return to page 167 and select it.

YOUR ANSWER --- C

Let's straighten this out.

Work is the product of a force and the distance that this force causes something to move. That is, W = Fd. The phrase "the distance that this force causes something to move" should give you the clue necessary to answer the question. We agree that F does work because it causes the block to move horizontally over 0.70 meters, resulting in a work of 2.5 nt.

Does F_T cause anything to move? This force is a reaction force springing from the weight of the block. It holds the block in vertical equilibrium. In that case, how much work does F_T do?

Please return to page 99 and select one of the other answers.

YOUR ANSWER --- A

Not this one! The equation for work is in item 1(b).

Are you letting your notebook become sloppy? If you're going to make progress, you have to keep your notes neat and in order.

Please return to page 138 and choose another answer.

YOUR ANSWER --- B

Of course. All freely falling bodies have the same acceleration, namely, 9.8 m/sec^2 in the MKS system.

So, certainly, this need not be determined.

Go back to the original question by turning to page 157 now, and think it over once again.

YOUR ANSWER --- C

A little more thought on your part would demonstrate forcibly the error in this answer.

If you say that the magnitude of mgh' is greater than that of mgh, you are saying that at the completion of the first swing of the pendulum, there is more total energy in the system than there was at the start. In other words, you are saying that the pendulum is somehow creating energy out of nothing. If this actually could happen, what a different world this would be. We could set up pendulums wherever required as sources of energy; no longer would we need petroleum, coal, or atomic energy. Ours would be a miraculous, pendulum-operated civilization!

The Principle of Energy Conservation is often stated in these terms: Energy can neither be created nor destroyed; it can only be changed in form. Although this statement leaves much to be desired, it is essentially true.

So, at the end of the first swing--or any swing--the energy content of the bob of the pendulum can be no greater than it was at the beginning of the swing.

Please return to page 81 and select a more suitable response.

YOUR ANSWER --- B

Almost, but not quite. Perhaps you noted that the units given were pounds and feet, but thought that work must always be expressed in joules. The principle of work as the product of force times distance in the direction of the force is unchanged. However, there is no single word in the English system for "joule" in the MKS system. You should be able to select the right answer now.

Please return to page 87 and choose again.

YOUR ANSWER --- D

Well, let's see.

From the definition of power we have:

$$P = W/t$$

We want to determine work, so we'll solve this for W:

$$W = Pt$$

The power is 500 watts and the time is 1 minute. Since a watt is a joule/second, we can substitute j/sec for watts so that:

$$W = 500 \text{ j/sec} \times 1 \text{ minute.}$$

Note that the time units are different so that you cannot cancel them and come out with joules as the unit of your answer.

Please return to page 121. Think this out; then make another selection.

YOUR ANSWER --- D

One of the answers is correct.

You may have made a mistake in arithmetic. Repeat the solution; you can determine the right answer. Remember that weight is a force, not a mass.

Please return to page 170 and try again.

This page has been inserted to maintain continuity of text. It is not intended to convey lesson information.

AMP LESSON 12 WORKSHEET Tape Segment 1

Please listen to Tape Segment . for Lesson 12 before starting to answer the questions below.

Data Item A: In Newton's Second Law, $F = kma$, $k = 1$ and is dimensionless.

In the Law of Gravitation, $F = G \frac{m_1 m_2}{r^2}$, G is the proportionality constant.

Here, k is not equal to 1, nor is it dimenless.

QUESTIONS

1. Which one of the following is the correct unit for work in the MKS system?

   A the kilogram-meter
   B the meter-newton squared
   C the newton
   D the newton-meter
   E newton per meter

2. Which one of the following is the defining equati...n for the physical quantity we call work?

   A $W = kFd$
   B $W = kmg$
   C $W = kF/d$
   D $W = kma$
   E $W = kFd/m$

3. In the defining equation for work, the proportionality constant k may be set equal to unity (1) because

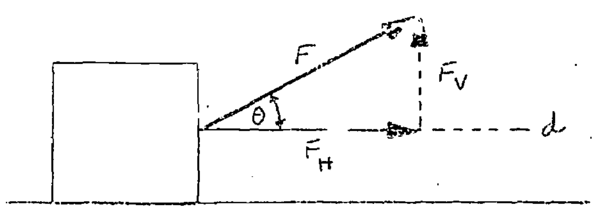
   A work turns out to be a scalar quantity.
   B work turns out to be a vector quantity.
   C we have not yet defined a unit of work so that we may now define it in terms of unit force and unit distance.
   D the constant of proportionality in a linear equation like the one which defines work is always unity.
   E the defining equation for work does not contain a fractional term, hence k must equal equal unit to keep the units correct.

Please return to page 119 of the STUDY GUIDE.

WORKSHEET

Please listen to Tape Segment 2 for Lesson 12 before starting to answer the questions below.

Data Item A: Refer to the diagram below.



QUESTIONS

4. Assume that θ in the diagram is 37 degrees and that F = 21 nt. If the block is caused to move 3.0 m in the direction of d, how much work is done? (The approximate values of some of the common trigonometric functions are given in Data Item B.

   A 16.8 joules
   B 63 joules
   C 7.0 joules
   D 50 joules
   E 5.6 joules

5. If the work in a horizontal direction results in constant velocity of the block, then all of the work is

   A being done against gravity.
   B being done against the vertical component of gravity.
   C being done against the horizontal component of gravity.
   D being done against the force of friction.
   E going into increasing the kinetic energy of the block.

6. The magnitude of the vertical component of F (21 nt) is

   A 2.1 nt B 0.6 nt C 1.1 nt
   D 48 nt E 13 nt

Data Item B:

	30°	37°	45°	53°	60°
sin	0.50	0.60	0.71	0.80	0.87
cos	0.87	0.80	0.71	0.60	0.50
tan	0.58	0.75	1.00	1.33	1.73

Please return to page 87 of the STUDY GUIDE

WORKSHEET

Please listen to Tape Segment [illegible] before starting to answer the questions below.

QUESTIONS

7. A wooden block is moving at uniform speed on a frictionless, horizontal table. The block is moving due east. In order to bring it to rest, you would have to exert

A a definite force to the east so that it would cause negative acceleration of the block.

B a very large force to the west to produce positive acceleration of the block.

C any force to the west that would cause negative acceleration of the block.

D a force to the north large enough to cause the block to decelerate.

E no force at all since the block will ultimately come to rest.

8. When the moving block in question 7 is brought to rest, it

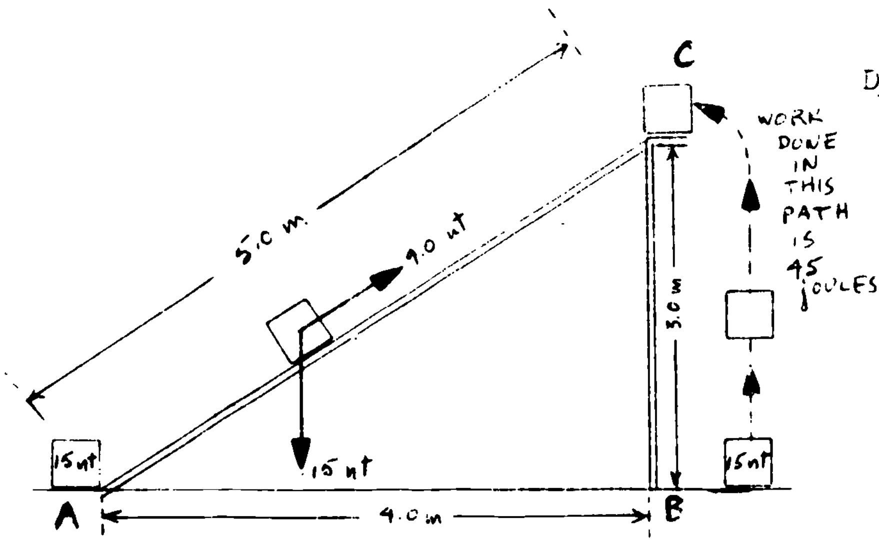
A must do some work on your hand.
B may or may not do work on your hand.
C does not do work on your hand.
D does work on your hand only if brought to rest in a relatively short time.
E must also reverse its direction if it is to do work on your hand.

9. Assuming that the block does work on your hand during the stopping process, then your hand

A must do an equal amount of work on the block in the direction of its motion.
B must do an equal amount of work on the block in the direction opposite its motion.
C must do more work on the block than it does on your hand.
D must do less work on the block than it does on your hand.
E may do either more or less work on the block depending on the time the force is applied.

PLEASE RETURN NOW TO PAGE [illegible] OF THE STUDY GUIDE

WORKSHEET



Data Item A.

All the questions on this worksheet relate to the diagram at the left.

QUESTIONS

10. Suppose the block is initially resting on the frictionless horizontal table at A. The work then required to move the block from A to B is

A more than 60 j.
B less than 60 j but more than 45 j.
C less than 45 j but more than 15 j.
D less than 15 j but more than 0 j.
E 0 j.

11. Which one of the following statements is not only relevant to this example but is also valid?

A The work done in lifting any weight to the top of this plane would be 45 joules.
B The work done in lifting a 15 nt weight to the top of any 3:4:5 plane is 45 joules.
C The potential energy acquired by a given mass raised to a given height is the same regardless of the path taken to this height.
D The K.E. acquired by the block sliding up the plane was equal to the K.E. acquired while going straight up.
E If the angle of the plane were increased by shortening AC and AB, more work would be required to slide the block up to C.

PLEASE RETURN NOW TO PAGE 55 OF THE STUDY GUIDE.

WORKSHEET

Please listen to Tape Segment ... this Worksheet. You will also need the ... film ... CONSERVATION OF ENERGY.

Data Item A: K ... [illegible] ... $\frac{1}{2}$ mv

but average ... [illegible] ... = d

so ... [illegible] ... $\frac{d^2}{t^2}$

hence $KE = \frac{1}{2} m \frac{d^2}{t^2}$

Now, since the mass of the glider and the distance it travels in all parts of the experiment as it passes the photocell are both constant, then $\frac{1}{2} md^2$ is a constant.

hence $KE = \frac{k}{t^2}$

which enables us to say that the relative kinetic energy of the glider in each trial is inversely proportional to the square of the time recorded on the film tape.

Data Item B: The data taken during the film is recorded separately for each individual segment of the three segments in the film.

I. In the first trial, the work done by the constant force device acting on the glider is assigned a value of 1 unit; since the force was doubled in the second trial -- over the same distance -- the work in this trial is 2 units.

Time for the first trial = 6.0 divisions = 0.60 sec
Time for the second trial = 4.3 divisions = 0.43 sec

Going from trial 1 to trial 2, the work done on the glider was doubled, hence the KE of the glider should have doubled if energy was being conserved. To find out if this happened, we must square the times and set them up in inverse ratio.

$$\frac{KE_1}{KE_2} = \frac{(t_2)^2}{(t_1)^2} = \frac{(0.43)^2}{(0.60)^2} = 0.5$$

This tells us that the ratio of KE's, which should be 1:2 or 1/2 or 0.50 is experimentally determined as 0.5.

Remembering that percentage error is found by subtracting the experimental value from the computed value (or vice-versa, to obtain a positive result) and dividing this difference by the computed value, you can now answer question 12 on the next page.

(next page, please)

12. The percentage error for Part I. is

A less than 1%. B less than 2% but more than 1%.
C less than 3% but more than 2%. D 3%.
E 4%.

II. By doubling the elevation of the track, the gravitational potential energy is doubled since the weight of the glider remains the same, i.e., PE = weight x height. By making the height twice as great, the PE becomes twice as great. This means that the KE of the glider in the second case should double, and again the ratio of KE_1/KE_2 should come out to be 1/2, or 0.50.

Times recorded on tape: When PE = 1, time is 0.51 sec.
When PE = 2, time is 0.36 sec.

Now calculate the <u>measured</u> ratio KE_1/KE_2. Don't forget to square the times.

13. The percentage error for Part II. is (to 2 sig.figs.)

A zero. B between zero and 1%.

C between 1% and 1.5%.

D between 1.5% and 2%.

E between 2% and 3%.

III. By doubling the compression of the spring, the elastic potential energy of the spring is <u>quadrupled</u>.

Times recorded on tape: For smaller compression, 0.61 sec.
For larger compression, 0.30 sec.

14. The percentage error for Part III. is (to 2 sig. figs.)

A zero. B between zero and 2%.

C between 2% and 3%. D between 3% and 5%.

E more than 5%.

PLEASE RETURN NOW TO PAGE 138 OF THE STUDY GUIDE.

AMP LESSON [illegible]

HOMEWORK PROBLEMS

1. A man applies a constant force of 32 nt to a cart. This causes the cart to move a distance of 10 m in 8 sec. (a) How much work did the man do on the cart? (b) What was the power of the man in watts in this action?

2. Twelve 100-watt lamps burn steadily for 10 hours at full rating. Assuming that a generator operating at 100% efficiency supplied the required electricity, how much work did the generator do?

3. A hill rises 10 m for every 100 m of its slope. A car weighing 4000 nt moves up the hill at 55 m/sec. What is the apparent power of the engine during this period?

4. A constant force is applied to a 4-kg mass causing it to accelerate from rest to a velocity of 5 m/sec over a distance of 10 m. Calculate the magnitude of the constant force involved in this action. (Use energy considerations in solving this problem.)

5. A 2-kg block of copper slides along a floor as a result of an impulse previously applied to it. After a time, its initial speed of 4 m/sec has decreased to 1 m/sec. (a) How much work did the friction force exerted by the floor on the block do? (b) If the reduction of velocity described above occurred over a distance of 10 m, what was the magnitude of the frictional force?

6. An automobile of mass 1000 kg rolls down a hill that is 70 m high and then immediately up an adjacent hill that is only 50 m high. What is the kinetic energy of the car just as it arrives at the top of the second hill? (Ignore frictional effects.)

7. An electron has a mass of 9.1×10^{-31} kg. If an electron is accelerated in a betatron so that it is moving with 1/10 the speed of light, what is its kinetic energy? (The speed of light is 300,000 km/sec).

8. A stone of mass 0.2 kg falls freely from the top of a cliff 50 m above the ground. At the instant that it is 40 m from the ground, what is the magnitude of its kinetic energy?

9. An archer, applying an average force of 8.0 nt to a bow-string, pulls the center of the string back a distance of 20 cm. The arrow fitted to the string at this point has a mass of 0.2 kg. What velocity will it have just as it leaves the bow after it has been released by the archer?

10. The bob of a pendulum rises 0.1 m from its lowest point at the top of its swing. If its mass is 1.0 kg, how fast is it moving at the lowest point of its swing?